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TITLE OF THESIS... PROCESSING OF POTATO GRANULES WITH THE AID OF FREEZE-THAW TECHNIQUE

UNIVERSITY... THE UNIVERSITY OF ALBERTA

DEGREE FOR WHICH THESIS WAS PRESENTED... DOCTOR OF PHILOSOPHY

YEAR THIS DEGREE GRANTED... 1973

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PROCESSING OF POTATO GRANULES WITH THE AID OF FREEZE-THAW TECHNIQUE

by

© BUNCHA CORAIKUL

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF FOOD SCIENCE

EDMONTON, ALBERTA

SPRING 1973

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled PROCESSING OF POTATO GRANULES WITH THE AID OF FREEZE-THAW TECHNIQUE submitted by B. OORAIKUL in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

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Supervisor

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External Examiner

Date December 20, 1972

ABSTRACT

A direct technique for production of potato granules, using a freezing and thawing step as an integral part of the process, was proposed. Investigation of the changes taking place in the potatoes during processing showed that: cooking renders pectic substances more soluble; freezing and thawing, and increasing temperature both reduce the amounts of released starch and water-soluble pectic substances available for binding the cells together, and hence enable the cooked potatoes to be mashed with a very low amount of damage to the cells; and that both surfactants, and freezing and thawing are essential for the success of the process. The proposed process has fewer stages than the currently used commercial processes. Further, these studies indicate that a comparable or better product is obtained more easily with the freeze-thaw process than with other processes for potato granule production.

Equipment and processing conditions employed in pre-drying, granulation, and drying were studied. Modification of a fluidized-bed dryer to be used for pre-drying and granulation is described. The temperatures and velocities of the air, and the speeds of the stirrer were determined for each of these steps. Drying rates of the mashed potatoes during each step were investigated and it was found that a long constant-rate period during the pre-drying step could be achieved with the aid of the freeze-

thaw and stirred-bed techniques.

The physical characteristics of the reconstituted product were studied. A sensory evaluation panel found that the textural characteristics of the product were comparable, or slightly superior, to some products commercially available.

The sensory panel also provided evidence that glueyness is more strongly correlated to the overall textural quality of mashed potatoes than firmness and smoothness. Attempts to measure the glueyness of mashed potatoes objectively produced results which suggest that the method may be suitable for quality control and product development in the dehydrated mashed potato industry.

ACKNOWLEDGEMENT

I wish to record my sincere appreciation to Dr. G.J.K. Packer, my supervisor and friend, who in many ways made this study possible.

Sincere thanks are due to staff members in the Department of Food Science, particularly Dr. L.P.L. Clegg, Dr. D. Hadziyev, and also Dr. C.T. Phan of the Department of Plant Physiology and Biochemistry for their criticisms and helpful suggestions.

To Mr. D. Jericevic, for his assistance in parts of the experimental work, I owe my appreciation.

My sincere gratitude is also due to Mr. Jack Iwabuchi, I & S Produce, Edmonton, for the Southern Netted Gem potatoes used in these experiments; Alberta Agricultural Research Trust and the Alberta Potato Commission, and the Department of Food Science for financial assistance.

Also, the University of Alberta Computing Services, particularly Mrs. C. Christie and Miss P. Cruden, for financial and technical assistance in the use of the IBM 360/67 computer for the production of this thesis.

Finally, I wish to record my appreciation to Annie, my wife and Suwanee, my daughter, for their encouragement and understanding throughout the course of this study.

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SECTION A. GENERAL INTRODUCTION

Potatoes and Potato Products

The potato, *Solanum tuberosum*, L. is one of the largest food crops produced in the world to-day (The National Potato Council, 1969), and has been a very important part of the diet of people in many parts of the world for over a century. In the United States of America, due to the accelerated scientific and technological development in the last few decades, the efficiency of potato production has markedly increased to the point that the potato industry is now faced with the problem of surplus resulting in a great reduction in price. The per capita consumption, on the other hand, declined gradually from 136 lbs per person per year in 1931 to 101.9 lbs per person per year in 1952. With the advent in technological advance in processing in recent years, however, the per capita consumption is now on an upward swing due to the availability of the potatoes in many processed forms, the convenience and the quality of which attract more consumers and higher consumption.

Processes for Potato Granule Production

Among the dehydrated potato products developed since early this century, dehydrated mashed potatoes are one of the most popular, and production is still increasing in

volume and efficiency. The instant dehydrated mashed potato includes potato granules and potato flakes. Together they comprise the bulk of dehydrated potato products and have become widely accepted in both consumer and institutional markets (Feustel et al., 1964). Potato granules, the subject of the present studies, are dehydrated, pre-cooked potatoes in granular form that can be quickly reconstituted to mashed potatoes by mixing with hot or boiling liquid. They were first developed as a World War II military item in England, and were introduced into the United States for home use in 1947 (Feustel et al., 1964). Early technological development of potato granules have been adequately reviewed by Olson and Harrington (1955), Feustel et al. (1964), and Gutterson (1971). Many patents have been issued concerning processing techniques, improvement of the processing techniques, and equipment used in processing of potato granules. Greene et al. (1949) hold a patent on "Freeze and Squeeze" method which was briefly used during World War II. The practice was discontinued early in the nineteen fifties due to the organoleptic inferiority, and the rather low bulk density of the product. Rivoche (1951a, 1951b) attempted to spray dry potatoes by first freezing the cooked potatoes, and then reducing them to a snow mist in a hammer mill. As yet no successful adaptation of spray dryer has been worked out to produce potato granules with acceptable quality. Heisler et al. (1953) used solvent extraction to produce potato granules. The process, however, involved many stages of

extraction and distillation, and the final product inevitably contained traces of solvents employed. Furthermore, the loss of some soluble materials during processing resulted in the product with inferior organoleptic quality. Volpertas (1944), Rendle (1945), Willetts and Rendle (1948), and Rivoche (1948, 1950) described in their patents the "add-back" process which requires recycling of substantial amounts of the previously dried granules (seed) to mix with the freshly cooked potatoes to reduce their moisture content down to levels at which granulation could be successfully achieved. Hendel et al. (1962a, 1962b) patented a direct method for processing of potato granules without recycling of the dry seed, by pre-drying the cooked potatoes to a suitable moisture level prior to conditioning at low temperatures and granulation. Carlson et al. (1970) patented the method for comminuting and drying of cooked food products together with their specially designed equipment for the purpose. Their method is another attempt to avoid recycling of the dry seed by mashing and straining the cooked potatoes into streams of air to dry them to fine granules. Boyle stated in 1967 that the add-back process was the only process being used commercially, and to the best of the author's knowledge is still the only process being used.

All the above mentioned attempts are directed towards one aim, that is to process cooked potatoes, which

contain 76-82% moisture, into dry, fine granules which contain about 6% moisture, have a high bulk density (0.8 gm/cc or greater), and when reconstituted the mashed potatoes would possess all or most of the organoleptic qualities which are characteristic of the freshly cooked, mashed potatoes.

The difficulties in attaining this goal are, however, numerous. Much work has been done to overcome the problems, with results that the following generalizations can be made:

1. Only potatoes of high total solids, generally above 20%, can produce mealy and fluffy mashed potatoes.

2. The cooking of the potatoes has a profound effect on the process. The method of cooking, i.e. whether water or steam is used as heating medium; cooking time and temperature, are all important. Both under- and over-cooking have detrimental effects on the potatoes with the results becoming apparent in the subsequent stages of processing (Hendel et al., 1962a), as well as in the final product.

3. Mashing is one of the most critical steps in determining the success of the subsequent processing steps and quality of the final product.

It is the first stage in which the cooked potatoes are subjected to mechanical forces in order to subdivide them into smaller units of single cells or aggregates of few cells. If the cells are broken the gelatinized starch will be released resulting in undesirably sticky or gluey mash which not only makes the succeeding stages of processing much more difficult, but also produces an unacceptable product. Temperature of the potatoes during mashing; time, and equipment used for the purpose determine the success of this step.

4. Granulation (i.e. final size reduction before drying to about 6% moisture) is also a very critical step in the processing of potato granules. The extent of damage, the granule size, and the percentage of fine granules taken as final product are determined essentially at this stage of processing. It has been found that only when the moisture content of the mash is reduced to within the range of 35-45% that granulation can be accomplished satisfactorily (Bunimovitch and Faitelowitz, 1936). The pre-drying methods, and the temperature, time, and equipment used in granulation play important roles in the success of this step.

5. The method of feeding the moist granules into the dryers, and the method and equipment used in drying of the granules also influence, to a certain extent, the organoleptic quality and physical characteristics of the final product.

The processes referred to above are not understood well enough in terms of the raw material and its response to processing to overcome all of the problems met in the processes.

The "Add-Back" Process

The most successful to date is the add-back process, but problems in obtaining a high quality product are still encountered in the industry. In the add-back process the potatoes are partially cooked, cooled and held for about half an hour. The potatoes are then completely cooked, mash-mixed with the seed, conditioned at room temperature or lower for at least one hour after which they are granulated and finally dried. Each of these steps needs relatively precise control, and are hence subject to error which may result in an unsatisfactory product. The most disadvantageous characteristic of this process is that about 84-90% of the previously dried product has to be recycled as seed to be mixed with the freshly cooked potatoes. This means only 1/10 to 1/6 of the dry potatoes coming from the

dryer is product; the remainder stays in the system (Gutterson, 1971). Thus, the dehydration equipment must handle 6-10 times as much material as is actually packaged. As the process involves recycling, a substantial part of the potatoes is, thus, repeatedly subjected to mechanical forces in mash-mixing, granulation, and drying which may result in an unnecessarily high proportion of damaged cells in the product. Furthermore, if a given volume of the seed material contains a high proportion of broken cells, or is highly contaminated with microorganisms, e.g. from the mash-mixing and/or conditioning steps, several times this volume of final product will also be imparted with these undesirable characteristics to some extent.

Hendel et al. (1962a, 1962b) tried to avoid the disadvantages of the "adding-back" in their process. Their technique, however, requires separate pre-drying equipment such as drum dryer or belt-conveyor dryer. The process gives a relatively high proportion of coarse fractions (+16 mesh) which must be discarded or used as an animal feed ingredient. Moreover, the process requires a long conditioning period (up to three hours at room temperature or lower) which may subject the product to detrimental microbial or chemical changes. Also, in the granulation step, the pre-dried potatoes are subjected for about one hour to continuous compression and shearing, which, though mild, may have an adverse effect on the potato cells.

The Present Work

During the development of a technique for freeze-drying of cooked potatoes in a freeze-drying company in New Zealand in 1968, the author observed the importance of the freeze-thaw technique as a means to pre-treat the cooked potato tissue. He found that the use of freeze-thaw stage greatly increased the capability of the potato cells to withstand mechanical forces, such as those in mashing or granulation with subsequent improvement in product quality.

Since it appeared that a process using the freeze-thaw technique could well produce a product superior to the instant mashed potato products available at that time in New Zealand using a much simpler and hopefully more economical process, and also because existing processes are not well understood in terms of the raw material and the changes induced in it by the different stages of processing, the present project was proposed. Areas chosen for detailed study include the following:

1. Effect of cooking on pectic substances: To further substantiate the hypothesis that cooking weakens the cell binding forces, changes in pectic substances in potatoes due to cooking and processing were determined using a modified carbazole method.

2. Effect of temperature on firmness of cooked potatoes: The dependence of the firmness of cooked potatoes

on their temperature, and the relationship between temperature of mashing and the extent of cell damage on mashing was investigated using compression and puncture tests and a microscopic examination method.

3. Effects of surfactants and the freeze-thaw process on gelatinized starch and pectic substances: The methods by which the cell binding strength in mashed potatoes, contributed by released starch gel and pectic substances, could be reduced were studied. The effects of surfactants as well as freeze-thaw process on starch in cooked potatoes were determined. Possible effect of surfactants on water-soluble pectic substances was also studied.

4. Physical properties of mashed potatoes in freeze-thaw process: To obtain data of physical properties of mashed potatoes necessary for calculations concerning the freezing and thawing steps, the overall heat transfer coefficient of the mashed potatoes during freezing in an air blast freezer was determined with the aid of Plank's equation.

5. Processing conditions for pre-drying, granulation, drying, and cooling: The essential data concerning pre-drying, granulation, drying, and cooling such as air temperature, air velocity, stirrer speed, and drying rate were obtained by conducting processing experiments

using a modified fluid-bed dryer.

6. Physical characteristics of product: Characteristics of the product, such as particle size, bulk density, proportion of broken cells, and moisture content were determined.

7. Subjective evaluation of reconstituted product: Texture panels were conducted to compare the textural characteristics of the product obtained with the proposed method with commercial products and freshly mashed potatoes. Overall rating of each product was also obtained.

8. Objective evaluation of reconstituted product: Firmness, glueyness, and density of the mashed potato products were measured. Correlations between each characteristic and the overall rating of the products were calculated to determine which characteristic is most useful as a parameter for objective textural analysis.

LITERATURE REVIEW

THE DEVELOPMENT OF PROCESSING TECHNIQUES FOR POTATO GRANULES WITH FREEZING AND THAWING AS AN INTEGRAL STEP

Greene et al. (1948) found that two results are achieved by freezing the cooked potatoes, i.e. a remarkable toughening of the cell wall, and a formation of free moisture, about 50% of which can be easily expressed from the potatoes after thawing without damaging the cells. They found that a slow rate of freezing had no detrimental effect on the cooked potato cells, contrary to the common belief. The toughening action due to freezing, however, was found to be reversed by reheating of the cells. Hall (1953) found that the cell walls of the cooked, frozen, and thawed potatoes underwent changes by wrinkling, shrinking, or crystallizing. He found that with longer freezing times, more water could be expressed from the thawed potatoes. Bretzloff (1970), however, found no appreciable change in the potato cell size due to cooking, or freezing and thawing. Longree (1950) reported that slow freezing of cooked potatoes resulted in a "dry cottony" texture in the unmashed potatoes upon thawing due to the reticulation or retrogradation of the cell contents. Harrington et al. (1951) reported that slow freezing, or quick freezing followed by slow thawing of cooked potatoes causes a freezing-out of water from the solubilized starch, leaving a firm structure that will maintain its physical properties

throughout subsequent dehydration. Reeve (1967a, 1969) also observed that freezing and thawing of cooked potatoes reduced the swelling capacity of the gelled starch and influenced its textural properties. This had advantageous effects in the manufacture of granules by rendering them more friable after thawing so that granulation is readily accomplished.

In general, the necessary stages in the proposed processes for production of potato granules using the freeze-thaw process are as shown in the flow chart of Figure 1.

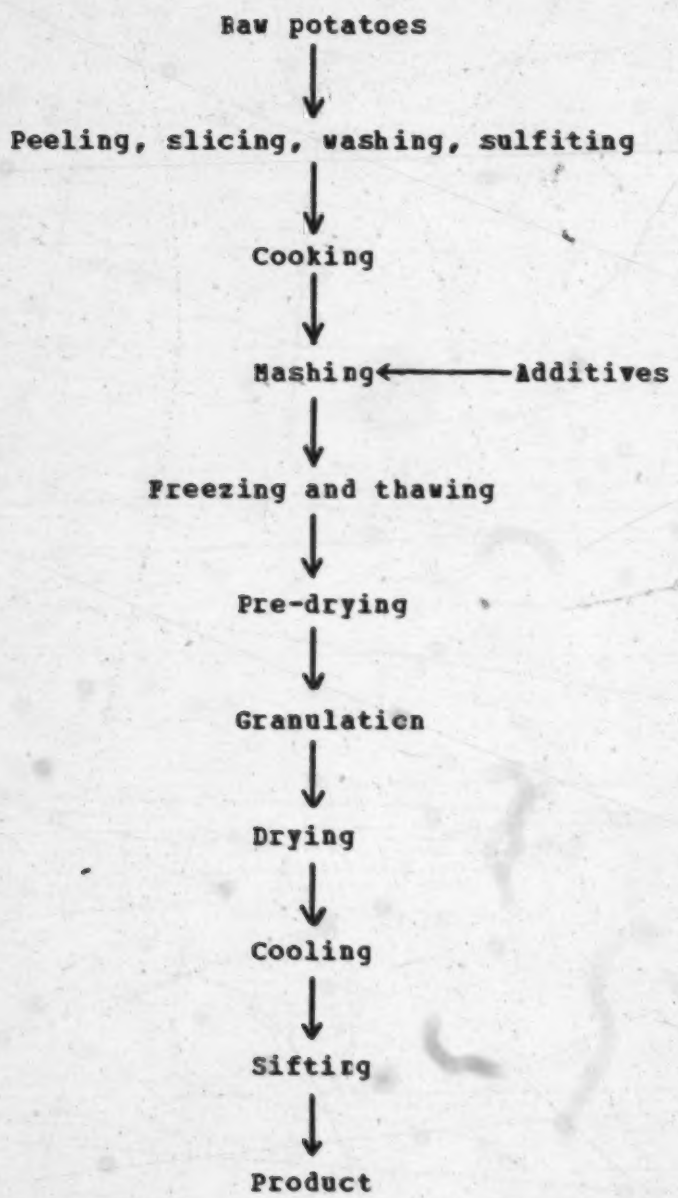


Figure 1. Flow chart for freeze-thaw process.

I. PEELING, SLICING, WASHING, AND SULFITING

The methods for peeling, slicing, washing, and sulfiting can be any standard methods used in research or industry. Abrasive peeling has been found, normally, to result in excessive loss of potato tissue with the peels. Steam peeling or lye peeling reduces the loss considerably. Dry lye peeling, a recently developed technique (Graham et al., 1970), is claimed to reduce both peel loss as well as amounts of waste to be treated.

The peeled potatoes may be sliced cross-sectionally into rings of about 1/4 in thick, or longitudinally into strips of about 1/2 in x 1/2 in. This is to facilitate uniform and rapid heat transfer during cooking.

Thorough washing of free starch granules from potato slices is necessary to avoid stickiness on the surfaces of the cooked potato pieces due to the gelatinization of the exposed starch granules. If not properly washed, the gelatinized free starch contributes to the "pastiness" of the final product when reconstituted.

Sulfiting by soaking the potatoes in 0.5% sodium bisulfite solution for about 5 minutes has been found to be adequate for inhibition of enzymatic browning of the potatoes. The absorbed sulfite can also contribute to the prolonged shelf life of the granules. This is due to its

effectiveness in the inhibition of non-enzymatic browning and microbial growth (Feinberg et al., 1967). (To further improve the storage life of the product, however, additional amounts of sodium bisulfite may be introduced at the mashing stage so that the amounts of the preservative in the final product may be increased up to 400 ppm., calculated as sulfur dioxide, as required by the U.S. military specification (Feustel et al., 1964)).

II. COOKING

Cooking in potato processing serves to gelatinize starch granules contained in the storage cells, solubilize pectic substances in the middle lamella and to prepare the potato tissue for mashing and the subsequent drying operations (Kintner and Tweedy, 1967). The ideal cooking techniques are those which will produce maximum mealiness, which is a desired textural characteristic, from any given potato. Undercooking results in unmashed lumps and subsequently, higher amounts of broken cells, while overcooking causes sloughing or excessive tissue softening, and hence more damaged cells (Severson et al., 1955; Harrington et al., 1959).

Either steam or boiling water can be used as a heating medium for cooking potatoes. In boiling water, however, loss of some soluble solids such as sugars, proteins, ascorbic acid, solubilized starch, and metal ions

occurs through leaching. For some substances (e.g. solubilized starch, reducing sugars, amino acids and certain metal ions) this may be beneficial. It has been found that excessive extracellular amylose leads to stickiness in mashed potatoes; reducing sugars and amino acids produce non-enzymatic browning reaction (Burton, 1945); and iron is thought to be involved in the after-cooking darkening of the potatoes (Hughes and Swain, 1962). In other cases, however, the loss of these soluble solids results in the loss of organoleptic qualities of the product as well as direct economic loss. Steam cooking is considered to be the most satisfactory method and was chosen as the cooking method in the present studies.

Pre-cooking or partial cooking prior to complete cooking has been reported to increase mealiness of the dehydrated products and to firm the potato tissue (Reeve, 1954; Cording and Willard, 1957; Nelson et al., 1962; Potter et al., 1959; Harrington et al., 1959; Reeve, 1969). Soaking in cool water before and after cooking has been claimed by Hendel (1961) to improve granule texture.

When the potatoes are cooked two important components of the potatoes, from granule processing point of view, are affected viz. starch and pectic substances.

1. Effects of cooking on starch

Starch comprises between 65 and 80% of the dry

Table 1. Proximate analysis of white potatoes.

	Average, %	Range, %
Water	77.5	63.2-86.9
Total solids	22.5	13.1-36.8
Protein	2.0	0.7- 4.6
Fat	0.1	0.02-0.96
Carbohydrate:		
Total	19.4	13.3-30.53
Crude fiber	0.6	0.17-3.48
Ash	1.0	0.44-1.9

(From: Schwimmer and Burr (1967)).

weight of the potato tuber and is calorically the most important nutritional component.

Table 1 gives the proximate analysis of raw, white potatoes. In a raw tuber, starch is present as microscopic granules in the leucoplasts lining the interior of the walls of the cells of the parenchyma tissue. The granules are ellipsoidal in shape, with an average size of about 100 by 60 microns. Hall and Sayre (1970) used electron microscopy in examination of potato starch granules and suggested that each starch granule is surrcunded by a membrane. Ohad et al. (1971) observed this membrane at all stages of tuber development, and stated that it was derived from plastid envelope. Ohad et al. presented evidence to show that if the potato tuber is stored at a temperature of about 40°F (4.5°C) this membrane disintegrates, and a reduction in starch content and an accumulation of sugars occurs. The disintegration of the membrane was thought to have some role in the preservation and maintenance of the starch granule. At high temperature storage, (50°F (10°C) and higher), this phenomenon was not observed. Reeve (1967b) found a slight increase in starch granule size with the increase in storage temperature. In fact, it is a common practice in the processing industry to "recondition" the potatoes which have been previously stored at 40°F (4.5°C) or lower, at a temperature of around 75°F (18.5°C) to reduce the amounts of the accumulated sugars and improve the processing qualities

of the potatoes.

Starch consists of two main components: amylose, which is a polydisperse polymer of α-1,4-linked glucosyl residues with little branching; and amylopectin, which is a highly branched-chain glucose polymer in which the side chains are attached through α-1,6 linkages (Schwimmer and Burr, 1967). Starch content has been correlated with textural quality of cooked potatoes by various workers. Their reports are somewhat contradictory. Unrau and Nyland (1957a, 1957b), for example, found high concentrations of amylose correlate with greater mealiness, while Bettelheim and Sterling (1955), on the other hand, found no relationship between the chemical nature of starch and potato texture. Barios et al. (1961, 1963) found a greater percentage of large starch granules to be associated with high specific gravity of raw potatoes and mealiness of the cooked product. Reeve (1967a) concluded that there are wide varietal differences in the relationship between starch characteristics and textural qualities, and even within one variety itself.

Upon cooking of potatoes at temperatures of 190°F to 212°F all starch granules are rapidly gelatinized. As the process continues, some solubilized starch diffuses out of the cell through primary wall pits in the cellulose matrix (Reeve, 1954a). The tissue cells become distended by the swollen gel and tend to separate, particularly with "mealy"

tubers, due to the degradation of pectic substances between and in the cell walls (Reeve, 1967a). It was observed that potato tissue at this stage is relatively soft and flexible and lends itself to cell separation by mashing without excessive damage.

2. Effects of cooking on pectic substances

Pectic substances are polymers of polygalacturonic acid in which the carboxyl groups are more or less methylated (Schwimmer and Burr, 1967). They occur without exception in and between the cell walls of photosynthetic green plants.

Potter and McComb (1957) reported that the content of pectic substances in potatoes, based on the anhydrouronide content, ranges from 0.7 to 1.5% of dry weight of the potatoes. Sharma et al. (1959), on the other hand, reported the range of 0.8 to 1.5% based on fresh potato weight. Bettelheim and Sterling (1955) studied ten varieties of potatoes and reported the uronide content to vary from 1.1 to 2.1% dry weight basis, whereas Jaswal (1969) studying low and high specific gravity potatoes for French fries reported the uronide contents to be as high as 4.51 to 4.81% of dry potato weight. Hoff and Castro (1969) studied chemical composition of potato cell wall and reported that cell wall makes up 5-7.2% of dry weight of potatoes, and pectic substances make up 47.5-62.5% of dry cell wall, which would indicate that their tubers contained

between 2.4 and 3.9% pectic substances on a dry weight basis. Sharma et al. (1959) observed that pectin content of potatoes is related to their specific gravity and varies with different growing locations and cultural conditions. It would appear that the discrepancy in the reported uronide contents of potatoes are due mainly to the difference between the samples studied, while further differences may also have arisen from differences in the methods of analysis employed.

Bettelheim and Sterling (1955) found no direct relationship between the characteristics of pectic materials and potato texture. Personius and Sharp (1939) found that the decrease in cell adhesion after cooking is caused by the weakening of intercellular cementing material of potato tissue. They reported also that pectic solvents and precipitants could be used to soften tissue enough to allow easy separation of cells. Linehan and Hughes (1969b, 1969d), on the other hand, after postulating that tuber firmness of the cooked potatoes depends on the intercelluar adhesion found no significant correlation between amounts of polyuronide and intercellular adhesion except in the samples with low amylose levels. They are of the opinion that intercellular adhesion is strongly related to amylose levels in potatoes. Nevertheless, it can be concluded that when potatoes are cooked the tissue cells become distended by the swollen gel and tend to separate as pectic substances

between and in the cell walls are at least softened, if not completely degraded (Reeve, 1967a, 1970).

Pectic substances exist in two major forms: protopectin (Figure 2), which is the water-insoluble parent pectic substance which occurs in all plants and which, upon metallic ion displacement and restricted hydrolysis, yields pectin, which is composed of water-soluble pectinic acids or colloidal polygalacturonic acids (Figure 3) of varying methyl ester content and degree of neutralization (McCready, 1970).

Protopectin can be subdivided into two fractions according to their characteristics of solubility:

a. Protopectins that can be rendered water-soluble by treating with sequestering agents such as ethylenediaminetetraacetic acid (EDTA), tetrasodium ethylenediaminetetraacetate (Versene), ammonium oxalate, and sodium hexametaphosphate (Calgon). The presence of cations, especially Ca^{++}, leads to insolubility of low-esterified pectic substances and reduction of swelling of the higher esterified pectic substances by forming primary and secondary bonding between the pectin chains. When these ions are sequestered the bonds are broken or weakened, resulting in pectins which are soluble in water (Doesburg, 1965; Linehan and Hughes, 1969c).

b. Protopectins that cannot be rendered soluble by sequestering action. These may be strongly bound by

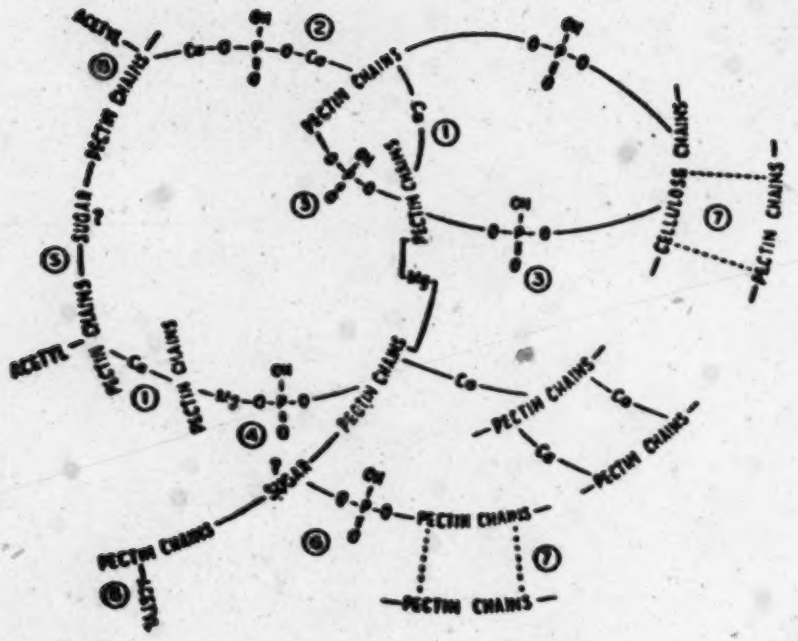


Figure 2. Model of protopectin according to Henglein (1958). (From Joslyn, 1962).

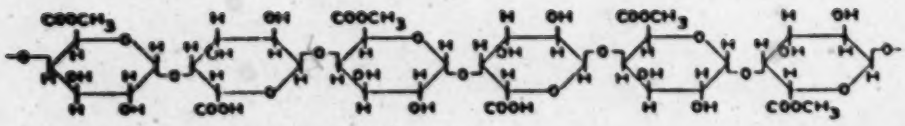


Figure 3. Part of polygalacturonic acid molecule, partly esterified with methanol (Doesburg, 1965).

mechanical enmeshing of filamentous macromolecules of pectic substances one with another or with other polymers in the cell wall (Doesburg, 1965). They may, however, be extracted by strong acid such as HCl at an elevated temperature (Bettelheim and Sterling, 1955).

In potatoes, the ratio of protopectin to pectin varies with variety, maturity, and cultural practice (Sharma et al., 1959; Bettelheim and Sterling, 1955; Linehan and Hughes, 1969b). This ratio changes on prolonged storage at low temperatures (e.g. 42°F) or on storage at higher temperatures (up to 75°F) for shorter periods of time (Sharma et al., 1959) as the protopectin is gradually changed into water soluble forms such as that which occurs in ripening fruit.

When the potatoes are cooked the heat energy is thought to disrupt or weaken some of the bonds in protopectin molecules (Reeve, 1967a) resulting in the increase in water-soluble fraction of the pectic substances (Bettelheim and Sterling, 1955; Jaswal, 1969). More work needs to be done, however, to elucidate the changes in pectic substances taking place during the course of processing.

III. MASHING AND POTATO FIRMNESS

1. Mashing processes

Mashing is one of the most critical steps in processing of potato granules in that it determines the extent to which the cooked potato cells are separated and, consequently, the extent of damage sustained by the separated cells. The ease with which the cooked potato tissue can be mashed depends largely on the variety, specific gravity, starch content, and anatomical parts of the potatoes. The literature pertaining to mashing has been adequately reviewed by Reeve (1954a, 1959, 1970), Schwimmer and Burr (1967), and Linehan and Hughes (1969a).

Methods and conditions under which the cooked potatoes are mashed differ somewhat from one processing technique to the other. Greene et al. (1948) suggested separating the cells after they are cooked, frozen, thawed, and pressed or centrifuged. They reported that the damage sustained by the cells was minimized if the potatoes were so treated. Olson and Harrington (1955) suggested mashing with a high speed, planetary type mixer for a short duration and at relatively high product temperature to reduce mechanical damage to the cells. They also reported that in the add-back process, the immediate addition of the seed granules reduced product damage.

Harrington et al. (1959) reported that slow mashing of the fresh hot potatoes without add-back quickly produces a sticky mash. They recommended mash-mixing of hot cooked potatoes and seed granules in a covered container to

reduce damage. They also reported that mixing at room temperature produces more fine granules of high density than mixing at high temperatures but rapid cooling before completion of the mashing is very damaging.

Willard (1967) was of the opinion that potatoes have always been cooked wrongly because the high solids portions in the outer layers of the tuber (which require least heat treatment) have been receiving the most heat, and the center portions (which require the most heat) receive the least. He patented a method and equipment which combines cooking and mashing together by subjecting the potatoes which are being cooked to a continuous mashing action across a mashing cage which is made up of elongated parallel rods or wires. He claimed that with this method every part of the potatoes receives the optimum amount of heat treatment when mashed, and that the cooking time can also be reduced considerably.

Many other cooking and mashing methods have been suggested in the literature (Greene et al., 1948; Hendel, 1962; Griffon, 1969; Beck and Rainwater, 1969). However, no adequate explanation of the effect of different methods of mashing or of the effect of temperature of the cooked potatoes during mashing on the ease of mashing and extent of damage to the potato cells has been put forward.

2. Potato firmness

Mashing essentially involves the application of compressive and shear forces to the cooked potatoes so that, in effect, the individual cells can be separated from one another. The amount of force applied depends largely on the resistance of the material. In the case of cooked potatoes, this depends on the binding strength between the cooked cells. This strength may be collectively described as hardness or firmness of the cooked potatoes. The strength of the cell wall, on the other hand, determines how much force the cells can withstand without sustaining excessive damage.

Attempts have been made to measure the strength of both raw and cooked potato tissue, and to correlate it to the culinary quality of the cooked potatoes. Sharma et al. (1959) used a penetrometer to measure the firmness of the soft- and hard-cooking potatoes. They found that the pressure resistance of the tubers which remain hard after normal cooking is several times higher than that of the soft-cooking tubers. Le Tourneau et al. (1962) used the extent of sloughing, which is expressed in terms of amounts of cooked potato tissue retained on No. 10 sieve after lowering and raising ten times in distilled water, to measure the textural quality of the cooked potatoes. They reported a high correlation between sloughing and the subjective scoring method. Linehan and Hughes (1969a) pointed out that the firmness in the tubers is directly correlated with their starch content which varies from one variety to another and even between different regions of a

tuber of the same variety, and also with their intercellular adhesion. The same authors (1969d) used a simple puncture tester and the Wolodkewitsch tenderometer (Grunewald, 1957) to measure the firmness of cooked potatoes and concluded that there is no significant difference in the results obtained from the two methods, and that the results correlate firmness with the intercellular adhesion.

Bourne (1966) studied various parameters involved in a simple puncture test and showed that the force required to puncture a food depends on the area and perimeter of the punch and on the compressive strength and the shear strength of the food being tested. In 1969 de Man used a Kramer shear press and puncture tester to study the texture of raw Netted Gem potatoes and reported that shear force is directly related to sample weight, and that the rate of shear also had a significant effect on shear force when the Kramer shear press was used. Voisey et al. (1969) using puncture and compression tests to study raw Netted Gem potatoes from various locations as related to the quality of French fries made from them concluded that there is no significant difference in the results obtained from either of the tests. They reported, however, that elastic properties of the potatoes vary widely between and within tubers and thus careful selection of samples for the tests is very important.

A knowledge of the effects of temperature of the

cooked potatoes on mashing and the resultant product is necessary so that optimum conditions for the mashing step can be determined, and hence it is desirable that mashing process be studied, so that the important parameters involved can be identified.

IV. ADDITIVES IN POTATO GRANULE PROCESSING

Food additives have been commonly used in production of potato granules to improve product quality. There are four major categories of problems encountered both during processing and on storage of the product, viz. enzymic and non-enzymic browning, after-cooking darkening, oxidation, and textural quality, for which additives are used.

Sulfur dioxide or compounds that evolve sulfur dioxide, e.g. sodium bisulfite and sodium metabisulfite are commonly used to prevent enzymic and non-enzymic browning as well as after-cooking darkening. Chelating agents such as EDTA and some other chemicals such as sodium gluconate, sodium acid pyrophosphate, are also used to prevent the appearance of after-cooking darkening. Smith (1968) has adequately reviewed literature pertaining to the nature and prevention of these two categories of the problems.

The fat content of the potatoes is only about 0.3% (dry basis), but due to its high degree of unsaturation oxidative rancidity is an important factor in limiting the

shelf-life of potato granules (Smith and Davis, 1968). Butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), propyl gallate, citric acid, and other classes of antioxidants are normally added to the product to prevent the occurence of oxidative rancidity during the storage of the product (Smith and Davis, 1968; Boyle, 1967; Pader, 1962). Packaging of the product under an atmosphere of nitrogen is also used commercially to control the oxidative deterioration (Drazga, 1964; Boyle, 1967).

Textural quality of the product when reconstituted is probably the single most important characteristic of the product. The reconstituted potato granules should have a "mealy" texture, be free from pastiness or lumps, and should be smooth, i.e. the texture should resemble that of freshly mashed potatoes (Severson et al., 1955; Willetts and Rendle, 1948; Hendel et al., 1961; Hendel et al., 1962b; Pader, 1964). Though great care is taken during processing of the granules to minimize cell damage so that pastiness in the reconstituted product is reduced, the product obtained from most processing techniques still lacks some of the desired characteristics. Certain kinds of food additives have thus been introduced into the product, mostly during the processing, to improve its textural quality. Severson et al. (1955) noticed that addition of 0.25% dry basis of glycerol monolaurate during the mixing step improves the texture of the product. Harrington et al. (1960) reported that glycerol

monostearate either incorporated during the process or added to the dried granules also improves the texture of the reconstituted product. Smith and Davis (1963) observed that addition of sodium acid pyrophosphate at various locations in the processing line increases mealiness and prevents after-cooking darkening.

Numerous patents have been issued concerning the use of food additives, particularly the surface active agents (surfactants), in processing of potato granules to improve their textural quality. Hendel et al. (1962) patented the use of gums such as carrhagheen, algin, pectin, guar, arabic, tragacanth, agar, locust bean, acacia, and other natural edible polysaccharide gums, together with surfactants such as sodium or calcium stearate, glycerol monostearate, to impart mealiness and smoothness to the product. Pader (1962) patented the use of nonfat milk solids and distilled monoglyceride to improve the texture of the product produced from potatoes with low solids content. Pader (1964) used edible monoesters of a polyhydric alcohol and a saturated fatty acid such as stearic or palmitic as a means to produce potato flakes with higher bulk density without sacrificing its desirable rehydration properties. Hale et al. (1961) sprayed the "texture improver", which is usually a surfactant such as glycerol monopalmitate mixed with hydrogenated vegetable fat, on to the dried flakes to improve the textural quality of the product. Weiner and Hegarty (1969) patented the improvement of whipping

properties of a mashed potato product by incorporating monoglycerides and salts of lactylic acid esters.

Some manufacturers add quantities of skim milk powder as a texture and flavor improver, and the effect of the milk powder on the texture may be due to surface active components in the added powder. The mode of action of surfactants in improving texture is not well understood and hence studies of the effects of surfactants on the two important components of potato tissue that control the texture of the product, viz. starch and pectic substances, are necessary in order to understand this phenomenon, and to determine the optimum levels of surfactants that should be used.

1. Effects of surfactants on starch

Manipulation of the starch fraction in cooked potatoes during processing of potato flakes or granules has been extensively studied and applied in practice with considerable success. The most common methods of starch manipulation used in the processes such as the add-back process are pre-cooking (Reeve, 1954b; Harrington et al., 1959; Potter et al., 1959), and conditioning or tempering of the moist mix at low temperature (Olson and Harrington, 1955). All these methods are aimed at producing physico-chemical changes in the starch gel in cooked potatoes, namely retrogradation (Olson and Harrington, 1955), through

which the gel becomes less sticky and less soluble. Granulation is then easier to accomplish, and an improved texture of the product is achieved (Potter, 1954).

Retrogradation is a process whereby starch in the dissolved or hydrated state reverts to a water-insoluble form (Foster, 1965). It arises from the inherent tendency of starch molecules to bond with one another leading to an increase in crystallinity (Collinson, 1968). Retrograded starch, as well as retrograded amylose, is microcrystalline and normally exhibits the B-type X-ray diffraction pattern (Foster, 1965). Solutions of starch which have aged at room temperature or lower, undergo retrogradation, the process of which may be hastened by freezing the aqueous solutions; in this way, ordinarily stable solutions may be forced to retrograde (French, 1950).

French (1950) also reported that although some amylopectin preparations have a tendency to retrograde from solutions, the property is greatly exaggerated in pure amylose solutions. He also suggested that retrogradation can take place even in the solid state, (as in the staling of bread); and that the retrogradation can be arrested by swelling agents, by keeping the preparations above room temperature, or by removing their moisture. Potter (1954) in his study on changes in physical properties of starch in potato granules during processing reported that as moisture content of the potato decreases, rate of retrogradation

increases until there is about 30% water. Below this the rate begins to decrease until about 15% water where there is no measurable change in the rate of retrogradation. He concluded that the changes in the physical properties of starch play an important role during the tempering period in the production of potato granules, making the potato tissue more friable, and hence more suitable for the subsequent granulation.

The dependence of the rate of retrogradation on moisture content of the gel has also been demonstrated by Hellman et al. (1954) who showed that the rate is greatest between 30% and 60% moisture. This fact has been successfully utilized in the production of potato granules. It has been shown that granulation is improved by decreasing the moisture content of the moist mix, in the case of the add-back process, to the range of 45 to 35% (Olson et al., 1953). In this moisture range, the quantity of unretrograded amylose is significantly reduced during the "conditioning" period and the cells are therefore bound less strongly.

Another important property of starch, particularly the amylose fraction, is its ability to form "clathrates" with iodine and fatty acids. This class of compounds has been described as "non-stoichiometric compounds", or "inclusion compounds" (Birnbaum, 1963). The clathrates are formed with two distinct components: the host and the guest. The guest is retained in closed cavities or cages provided

by the crystalline structure of the host. The two components do not react chemically with each other. The host does not always consist of an ideal crystalline structure with an orderly lattice, but can, in certain cases, assume the form of channels which are open at both ends, permitting the guest molecules to lie within the channels, held in place by van der Waal's forces of attraction (Birnbaum, 1963).

In the case of starch, the linear fraction or amylose acts as a host forming a helical configuration to enclose the guest molecules. This phenomenon is strongly supported by evidence from selective precipitation and X-ray diffraction techniques (Radley, 1968; Birnbaum, 1955; Senti and Erlander, 1964). The complex formed between amylose and either iodine or the fatty adjunct is found to give the V-type X-ray powder pattern (Birnbaum, 1955; Senti and Erlander, 1964). In their review Hollo and Szeitli (1968) stated that in aqueous solution the amylose molecule forms a random coil which consists of linear segments of helical structure built of 2-20 helical turns, all of which contain 6-8 anhydroglucose units. The same authors also suggested that the amylose in aqueous solution forms inclusion complexes only when the H-bonds exist between primary and secondary hydroxyls in neighboring turns. Retrogradation can thus occur only if these bonds are split and reformed between various molecules, or within the same molecule but not between the neighboring turns.

This phenomenon has been extensively studied in connection with the staling of bread and its prevention. Various kinds of surfactants which can form clathrates with starch have been widely used to prevent or retard staling of bread which is the result of retrogradation process of the amylose fraction (Osman et al., 1960, 1961; Birnbaum, 1955, 1963, 1971; MacDonald, 1968; Elton, 1969; Jongh, 1961; Yasunaga et al., 1968). In his review MacDonald stated that the amylose fraction which is dispersed throughout the bread structure sets up a rigid gel network after cooling of the bread and gives a hardened, leatherly texture on staling. If the amylose forms clathrates, as when the surfactants are used, it will be prevented from forming the rigid network leaving the bread deformable and plastic even after storage.

It is believed that similar situations prevail when surfactants are used in the production of potato granules or flakes. The amylose fraction that may have diffused out from the gel matrix of the broken cells, or through the minute pits on the wall of intact cells, will form clathrates with the added surfactants. This formation of clathrates prevents the amylose from forming strong intercellular bonds, and hence the cells can be separated more easily in the mashing and granulation steps. Further, when the dried granules are reconstituted the released starch which may have accumulated during processing will be prevented from causing pastiness. The texture of the reconstituted mash will thus be desirably mealy.

Furthermore, the hydrophilic nature of the surfactants used will increase the wettability of the granules enabling them to reabsorb water more readily and uniformly.

The choice of the surfactants used is also important. Osman et al. (1960, 1961) showed that monoglycerides are the most effective clathrate-forming agents while di- and tri-glycerides have little or no effect on the starch gel. They also showed that monoglycerides with different fatty acids differ in their effectiveness in forming complexes with amylose, with polyoxyethylene monostearate (MYRJ 52) being the most effective. Birnbaum (1971) in his review, on the other hand, reported that glyceryl monopalmitin is the most effective starch complexer with glyceryl monostearate being the second most effective.

Osman et al. (1961) studied the iodine affinity of amylose, using eighteen surfactants, and reported that all surfactants with the exception of the diglycerides and hydrogenated soybean oil greatly reduce the iodine affinity of amylose. They also found that the reduction of the affinity is directly related to the percentage of the monoglycerides added. This report is in agreement with the works reviewed by Gracza (1965) who stated that iodine absorption of corn amylose can be blocked entirely by 10% palmitic acid; and that of Radley (1968) who stated that A fraction starch adsorbs fatty acid in preference to iodine. Senti and Erlander (1965), however, observed that in the

non-aqueous state most of the fatty acid in the complex is displaced on exposure to iodine vapor.

The concentrations of surfactants added by various workers appear to have been chosen arbitrarily, rather than by a systematic study of the effect of concentration of the surfactant on the amount of starch gel in the mashed potatoes. Further, it is not known whether the effects of freeze-thaw and surfactants are additive, and hence more work is required in this area.

2. Effects of surfactants on pectic substances

It has been shown that pectic substances in potatoes become more water-soluble during cooking thus facilitating cell separation during mashing. No hypothesis or experimental evidence, however, has been put forward to show what chemical or physical changes take place in pectic substances if surfactants are added to the potatoes during mashing. The effects of surfactants on pectic substances, particularly the water-soluble fraction, should thus be investigated in order to understand more clearly the beneficial effects obtained from the addition of surfactants in processing of potato granules.

The water-soluble pectic substances are colloidal polygalacturonic acids of varying methyl ester content and degree of neutralization which are capable of forming gels under suitable conditions (Doesburg, 1965). The galacturonic

moieties in the pectin chain are linked together by α-1,4 linkages similar to those in amylose chain (Meyer, 1960). The gel formation of the pectins is also quite similar to that of amylose. The pectin swells and slowly dissolves in cold water. The process is hastened by heating and agitation. The dissolved pectin forms a viscous colloidal solution which flows readily at ordinary temperatures (Priest and Setori, 1951). Lampitt and Money (1937) reported that the strength of pectin gel varies with temperature, acidity, concentration of the pectin, and concentration of sugar added. The strength increases with decrease in temperature; it remains relatively constant at pH 1-3 then drops sharply at higher pH's; it increases with the increase of pectin concentration, and increases with the amount of sugar added.

The water-soluble pectins between and within potato cell walls, which have been increased as a result of cooking, will form a gel network when the mashed potato is cooled to the setting temperature of the pectins. The result is a stiff mass which will be difficult to break up in pre-drying and granulation stages without further treatment such as freezing and thawing. Surfactants help reduce stiffness of the mass by complexing with the starch fraction, and may also affect the pectin fraction.

It is difficult, however, to study these hypothetical effects separately within the mashed potatoes

per se, hence a model system of pectin gel, using commercially available pectins, is probably the simplest way of investigating the phenomenon. Two major kinds of pectins are available commercially, i.e. rapid-set powder pectins, and slow-set powder pectins (Olliver et al., 1957). The rapid-set pectins are those with setting teperatures between approximately 65° and 95°C, whereas slow-set pectins are those with setting temperatures below approximately 70°C. The same authors reported difficulties in obtaining reproducible results when grading the rapid-set powder pectins. They found that the problem could be overcome by adding surface-active agents such as Teepol or fruit juices, but offered no explanation as to how they affected the pectins. This would indicate that the slow-set pectin is more likely to be satisfactory in a model system.

V. FREEZING AND THAWING

It may be that the success of the pre-drying and granulation steps will be strongly dependent on the freezing and thawing treatment of the mashed potatoes, the effects of which will also be clearly reflected in the textural quality of the reconstituted product.

The beneficial effects of freezing and thawing in potato granule production have long been recognized. Rendle (1945), in his patent of the add-back process, introduced freezing and thawing of cooked potatoes prior to the

admixing as an optional step. He found that when the mashed potato is frozen and immediately allowed to thaw the resulting product is more granular and less gelatinous in texture than when freezing is omitted. Bostock (1945) patented a technique for dehydration of potato powder based on his discovery that when the cooked mashed potatoes are frozen and then thawed at a temperature slightly above 0°C, the water is more loosely held by starch granules or by the cells, and a substantial portion of the liquid can then be separated mechanically, e.g. by pressing and/or centrifuging. Willetts and Bendle (1948), and Rivoche (1950) combined the technique patented by Bostock (1945) with the add-back process to reduce the amounts of the add-back seed. Greene et al. (1949) improved Bostock's technique by drying the dewatered potatoes to about 35-45% moisture before granulation to produce a finer powder. Greene et al. (1948) reported that two results are achieved by freezing the cooked potatoes, i.e. a remarkable toughening of the cell wall occurs, and approximately 50% of the moisture in the potatoes can be removed by pressing or centrifuging. They found that the macrostructure of the cooked potatoes was greatly altered by freezing and thawing, but the cells appeared unchanged and no ruptures were encountered. Neither rate nor temperature of freezing were found by these authors to affect the potato cells, but the time for which the frozen potatoes were held in the frozen state had a marked effect on the quality of the reconstituted product. They

reported grainy or gritty product produced from the potatoes that were held frozen for several days. Longree (1950), on the other hand, found cottoniness in the texture of reheated, frozen potatoes if freezing rate was slow. However, she found only slight change in the texture of quick-frozen potatoes after two months storage. Harrington et al. (1951) reported that slow freezing, and quick freezing followed by slow thawing have the same effect of causing a freezing-out of water from the solublized starch, and a firming of the potato structure. Hall (1953) studied the freezing rate of cooked potatoes and reported that slow-freezing can liberate 10% more moisture from the potato cells than quick-freezing, and that neither the freezing temperature nor the length of time the potatoes are held in the frozen state has any further effect on the amount of the water expressed. Reeve (1954c) reported that slow-frozen cooked potatoes have a slightly greater porosity when dried than the quick-frozen ones, and that freezing and thawing alter the moisture-reabsorbing capacity of the starch gels. Lazar et al. (1964) also agreed that the length of time the potatoes remain frozen is not critical in the effects of freezing and thawing. Potter (1954) and Reeve (1969) concluded that low temperature treatment of cooked potatoes results in retrogradation of starch gel.

Though it has been shown by some workers that the rate of freezing is not of great importance to the effectiveness of the treatment, it is believed, however,

that at least a moderate rate rather than rapid rate should be used for the processing technique being investigated. It is believed that with a moderate rate of freezing (e.g. in an air blast freezer at -10° to -20°F), sufficient water diffuses out of the cells into the intercellular voids while being frozen to permit rapid pre-drying, but that with very rapid freezing the amount of water diffusing from the cells is much less. The ice crystals formed by the moderate freezing rate should be sufficiently large to create minute passages through the cell walls to facilitate rapid drying in the subsequent drying steps and, consequently, give a faster reabsorption rate of the product when reconstituted.

VI. PRE-DRYING, GRANULATION, DRYING, COOLING, AND PRODUCT CHARACTERISTICS

1. Pre-drying and granulation

It has been established that moisture content of the cooked mashed potatoes has to be reduced from approximately 76-80% to about 35-45%, preferably less than 40%, before the mash can be successfully granulated to a fine powder without excessive cell damage (Volpertas, 1944; Rendle, 1945; Willetts and Rendle, 1948; Rivoche, 1950; Olson *et al.*, 1953; Cooley *et al.*, 1954; Neel *et al.*, 1954; Potter, 1954; Olson and Harrington, 1955; Severson *et al.*, 1955; Harrington *et al.*, 1959; Hendel *et al.*, 1961; Lazar *et al.*, 1964). Various techniques have been used to reduce moisture content of mashed potatoes to the desirable level.

These techniques include recirculation of the dried granules to mix with the freshly mashed potatoes as in the add-back process; freeze-thaw and press technique together with a reduced amount of add-back granules; and vacuum drying technique. More recently, partial drum drying and partial belt drying were introduced as pre-drying techniques in the direct process (without add-back) for potato granules (Hendel et al., 1961; Lazar et al., 1964). In this process the mashed potatoes are partially dried on either a drum dryer or a belt dryer until their moisture content is reduced to about 60%. The partially dried potatoes are then subjected to cooling and conditioning at low temperatures ranging from 100°F down to subfreezing. The conditioned potatoes are then granulated and dried through a critical moisture range of 50-35% in a specially designed "granulator-dryer". The granulator-dryer is a trough or U-shaped chamber with a longitudinal shaft with extended arms which carry a blade made of flexible material. When the shaft rotates, the blades wipe against the bottom of the trough. When the conditioned potatoes are charged into the trough they are subjected to continuous mild compression and shearing as the shaft rotates at about 5 rpm. The potatoes are granulated while their moisture is being reduced through the critical range by a stream of warm air which is blown through the length of the trough. The granulated potatoes may be dried in the same trough with air of higher temperature, or they may be blown over into another dryer by

a stream of air at higher velocity. The inventors claim that a high quality product is obtained with this processing technique.

It is apparent, however, that the above technique requires several steps of pre-drying, conditioning, further drying and granulation which require separate processing operations. The time required for conditioning, and drying-granulating, though substantially less than that in the add-back process, may still be sufficiently lengthy to allow the development of both undesirable chemical reactions and microorganisms. Furthermore, the process depends to a great extent on the quality of raw material and its previous treatment, e.g. special steam-cooking method which requires relatively precise combination of temperature and time, for the success of the subsequent granulating-drying. Nevertheless, the process is a considerable improvement over the add-back process in that it requires no recycling of the dry product.

2. Drying and cooling

Drying in the processing of potato granules is generally accomplished in two stages which involve two types of drying equipment, viz. pneumatic or air-lift dryer and fluidized-bed dryer (Olson et al., 1953; Neel et al., 1954; Cooley et al., 1954; Olson and Harrington, 1955; Severson et al., 1955; Harrington et al., 1959). In most cases, the

granulated potatoes are dried in the air-lift dryer to about 12% moisture, and finally dried to about 6% moisture in the fluidized-bed dryer towards the end of which the product is cooled to approximately room temperature.

The air-lift dryer consists, generally, of a main riser which is a round drying column about 30 ft high, an inverted truncated cone extending from the riser called a diffuser which is about 10 ft tall, a deflector above the diffuser to redirect the flow of the granules and, a separator body which is the main chamber housing the deflector, the diffuser, and part of the riser. The granulated potatoes are fed into the riser through a vibrating feeder and are carried upward by a hot air stream. The velocity of the hot air stream is 1,500-2,000 ft/min with a temperature of about 375°F. The air velocity is reduced to about 280 ft/min in the diffuser, and further reduced to about 45 ft/min at the deflector. The substantially dried product then travels downward to the bottom of the separator body and is collected through an annular collector while the moist air is exhausted through the outlet at the top of the separator body.

The granules from the air-lift dryer are then fed into a fluidized-bed dryer. The air at 70°F, and velocity of approximately 10 ft/min is blown through the bottom of a plate. Upon emerging from the upper face of the plate, the air separates the granules and moves them in such a manner

that the bed of granules behaves like a boiling liquid. The dried product moving in a horizontal direction is discharged over a weir at the other end of the dryer and may be further cooled in another unit of fluidized-bed dryer.

3. Product characteristics

a. Granule size and product bulk density

Dehydrated potato granules were developed with the aim of producing a quality product with high bulk density to save packaging, storage, and shipping costs. High bulk density is achieved by producing the finest possible granules. In the early development of the processing techniques it was not possible to subdivide the mashed potatoes into fine granules of essentially unicellular units. The product was generally sieved through 12-20 mesh sieve (Barker and Burton, 1944; Rendle, 1945; Greene et al., 1948; Rivoche, 1950). With further development, particularly with the introduction of the add-back process, it became possible to produce much finer granules, generally smaller than 60 mesh size, as the bigger particles could be recycled (Olson and Harrington, 1955; Neel et al., 1954). Cooley et al. (1954) found, however, that although the bulk density of smaller granules is higher, the rate of drying rather than the granule size is responsible for the important variations in bulk density. They found that the granules dried at slower rates have higher bulk density. Lazar et al., (1964) reported that with their direct processing technique the

bulk density of the granules can be varied from 0.4 to 0.9 gm/cc.

b. Moisture content of the product

In general practice, the moisture content of the granules varies from 4-7%. From the standpoints of economic feasibility and product quality, however, the aim is to produce the granules with about 6% moisture. Strolle and Cording, Jr. (1965) studied moisture adsorption characteristics of potato flakes and calculated their monolayer moisture contents to be between 5.1-5.8%. They are of the opinion that this moisture range is a good first target for good storage stability of dehydrated potatoes as the values agree well with data obtained from storage tests. They also found that this range of monolayer moisture is independent of variety and geographical origin of the potatoes.

c. Number of broken cells in the product

The proportion of broken cells in mashed potatoes is a relatively reliable indication (pastiness) of the reconstituted textural quality of the product (Greene et al., 1948; Hall and Fryer, 1953; Reeve and Notter, 1959; Reeve, 1963). Greene et al. (1948) reported that reconstituted potato granules with 20% broken cells were very pasty; those with 10-12% broken cells were average in pastiness; and those with 6% and lower were ranked superior

with no apparent pastiness. Hall and Fryer (1953) developed a simple method for microscopic count by stirring a small quantity of potato granules in boiling water (5 gm/200 ml) and using a few drops of the suspension to prepare a slide for microscopic examination. The counting of the broken cells was facilitated by staining the sample with dilute iodine solution. Reeve and Notter (1959) in their attempt to improve the method, however, argued that diluting the product with boiling water was undesirable as in general practice most of the products were reconstituted with water or mixture of water and milk at lower temperatures. They also contended that cell rupturing may continue during the microscopic examination if boiling water was used. In their improved method, they advocated the use of hot water of 130°-140°F for the purpose. They also found that in dilute suspensions the cells do not stain uniformly with iodine solution, and that excessively stained starch may obscure some of the ruptured cells. They emphasized the importance of the observer's ability to recognize a ruptured cell in making these counts.

VII. PRODUCT QUALITY

1. Flavor

The flavor of the reconstituted dehydrated mashed potatoes should be characteristic of freshly cooked potatoes and should not vary significantly from one product to

another. Cooked or burnt flavors should not be present, nor should off-flavors be allowed to develop during storage. A further source of flavor modification is that in some processing techniques surfactants and other food additives are added to the potato during processing to the point that the characteristic flavor of the reconstituted product is significantly different from that of freshly mashed potatoes. For example, appreciable amounts of skim milk powder may be added to the product either during or after the processing with the intention of improving the product texture as well as its acceptability, and the resulting flavor may be objectionable to some. In general, flavor of reconstituted potatoes has not been a difficult attribute to control, although processes in which some of the soluble solids are removed before drying (as in the "freeze and squeeze" process) have failed because of inferior flavor characteristics.

2. Texture

Textural quality of the product is the major characteristic that determines its acceptability, and is much more difficult to control than flavor. Much study has been done, both subjectively using texture panels and objectively using instrumental texture measuring devices, and quite a number of textural parameters have been used as indicators of the quality of the product.

a. Textural characteristics

Textural evaluation of mashed potatoes by sensory means has been consistently employed in the past in the development of processing methods as well as quality control of the product (Olson and Harrington, 1955). The textural characteristics of the mashed potatoes, however, have been rather loosely defined, and this has sometimes led to confusion in determining the quality of the product. Wood et al. (1955) used rubberiness of the reconstituted potato granules to judge their textural quality. The least rubbery product was judged the best. Mackey and Stockman (1958) judged mashed potato samples for their mealiness, dryness, and smoothness the highest of which designated the best. Kuhn et al. (1959) scored the mealiest mashed potatoes as the most desirable, and the soggiest the least desirable. Zaehringer and Le Tourneau (1962), and Cunningham et al. (1966) reported that mealiness in the mouth, and mealiness on mild mashing with a fork were the most sensitive methods for evaluation of the texture of cooked potatoes. Szczesniak and Kleyn (1963) reported that the typical descriptive words used to describe texture of mashed potatoes among 300 people they interviewed were creamy, fluffy, smooth, soft, and dry. None of these terms used were further defined by the authors. It appears, however, that all workers agree that mealiness, dryness, and smoothness are desirable characteristics, whereas rubberiness and sogginess are undesirable.

Szczesniak (1963) attempted to classify textural characteristics of various foods and correlate the textural parameters to the popular nomenclature. The textural characteristics were grouped into mechanical, geometrical, and "other characteristics". Mechanical characteristics were defined as the reaction of the food to stress which could be measured organoleptically by pressure exerted on the teeth, tongue, and roof of the mouth during eating. Geometrical characteristics were referred to the arrangement of the constituents of the food, and are reflected mainly in the appearance of the food product which is mostly sensed visually, though some can be sensed orally through the sense of touch and pressure. Other characteristics were defined as mouthfeel factors that could not be easily resolved on the basis of mechanical and geometrical properties. These characteristics were divided further into primary and secondary parameters. Mealiness which is a popular term, for example, was related to the secondary parameter of gumminess, and primary parameters of hardness and cohesiveness; and stickiness was related to the primary parameter of adhesiveness. Both mealiness and stickiness are classified as mechanical characteristics. Graininess and coarseness were related to the class of particle size and shape under geometrical characteristics; whereas dryness and wateriness were related to the primary parameter of moisture content (classified under "other characteristics").

It would appear then that there are three terms that may describe the main textural characteristics of mashed potatoes, viz. firmness, smoothness, and glueyness. These may simply be defined as follows:

i. Firmness, defined as ease of teeth penetration into the sample and the breakdown of the sample on chewing thereafter.

ii. Smoothness, defined as mouthfeel on chewing.

iii. Glueyness, defined as elastic response on chewing and tendency of the sample to stick to teeth or gums.

b. Sensory evaluation methods

The methods used most frequently for subjective assessment of texture of mashed potatoes include mouthfeel, and appearance or feel on manipulation (Zaehringer and Le Tourneau, 1962). Whatever method used, when the studies involve large number of samples which are judged over a period of time there is a tendency of the scoring scale to drift in value and meaning. This may be overcome by the use of labeled and/or coded reference or control samples (Boggs and Hanson, 1949; Wood et al., 1955).

Selection and training of panelists, number of samples per session, preparation of samples, and evaluation

methods are other important considerations in the organoleptic panel testing (Cartwright et al., 1952; Kramer et al., 1961). Kramer et al. (1961) advocated that in the selection of panelists the purpose of the test is to be considered first. If the purpose is only to obtain a consumer reaction then a trained panel is not needed or should be avoided, whereas if the purpose is to inspect or analyse the differences then superior panelists are to be selected. The same authors reported also that the efficiency of the panel increases with the number of times they are screened and trained, and that it is more advisable to increase numbers of the panelists and reduce the replications if it is desirable to obtain an indication of consumer preference.

The number of samples per session that can be reliably evaluated concurrently depends on the nature of the samples, the properties to be evaluated, and the skill and experience of the panelists. The major limiting factors of the panelists are sensory fatigue, boredom, and inattention (Cartwright et al., 1952). Kramer et al. (1961) reported that for a bland product such as potatoes five or more samples can be handled efficiently at one sitting.

Samples of a given material should be as uniform as possible in all aspects and properties. Cartwright et al. (1952) contended that if some of the properties are not to be evaluated, the levels of these properties should be

chosen and the samples adjusted to uniformity for evaluation of the other properties. Kramer et al. (1961) reported substantial improvement in the efficiency of testing when a reference sample was available, and that masking of color and other differences not being judged appeared to be most important. The same authors reported no definite advantage between scoring and ranking procedure as a method for evaluation.

Statistical analysis is a common and most important means used in evaluating the data obtained by a test panel. The appropriate analysis, i.e. variance, covariance, correlation, etc., varies with the statistical design of the particular experiment (Lowe and Stewart, 1947). With the analysis of variance the importance of interactions can be determined. Kramer and Twigg (1970) reported that one extremely important interaction in test panel results is the treatment x panelist interaction which, if significant, indicates that different panelists score the same sample differently. This means that there may be no best or worst sample but that each panelist may prefer a different sample.

c. Objective measurement of texture

Due to high cost and lack of precision of subjective appraisals of food products, objective measurement of food quality has been constantly under

investigation so that more precise and cheaper methods could be developed. Olson and Harrington (1955) reviewed earlier attempts to correlate viscosity and blue value index of reconstituted potato granules with their organoleptic quality. They reported that different raw material and different process used in processing the granules make these objective methods unreliable in their judgment of the quality of the products.

Mullins et al. (1957) developed a rapid physical measurement method to evaluate the quality of reconstituted mashed potatoes. They found that when a ball of rehydrated potato granules was allowed to fall upon a smooth surface the diameter of the resultant cake was related to either consistency or rubberiness of the product as determined by a panel of trained judges.

Smith and Davis (1963) used a modified L.E.E.-Kramer shear press to measure the textural changes in reconstituted potato flakes. They obtained reproducible results but found that temperature and moisture of the reconstituted flakes influenced the shear press readings.

Voisey and de Man (1970) converted a food mixer by attaching the bowl to an electronic dynamometer so that it could record the torque and energy used during mixing. They attempted to measure the consistency of the reconstituted potato flakes using this equipment and obtained good reproducibility within the samples.

Most of the attempts thus far have been to measure the overall textural quality of the mashed potatoes. As the textural quality of mashed potatoes is a complex combination of several distinct characteristics such as firmness, glueyness, and smoothness, a single measurement cannot hope to represent all these parameters, and hence it is doubtful whether those general methods do, in fact, measure the characteristic that is uppermost in the consumer's mind when evaluating the texture of the product.

Szczesniak (1963), after classifying the textural characteristics of food materials into separate categories and giving them appropriate nomenclature, proposed to correlate them with the specific objective measurement designed for each characteristic. Friedman et al. (1963) first developed a new instrument, the "General Foods Texturometer", which subjects the food sample to a cyclic deformation, to enable them to simulate crudely the breakdown of food on chewing. They used it to measure a range of textural parameters which include hardness, cohesiveness, viscosity, elasticity, adhesiveness, brittleness, chewiness, and gumminess. The output from the instrument was in the form of a force-time curve, and was termed a "texture profile" of the material. From the texture profile curve they then developed mathematical formulae to calculate values for each of the parameters.

Szczesniak et al. (1963) developed standard rating scales for mechanical parameters of texture by selecting several food products each of which possessed an outstanding textural property which is easy to perceive organoleptically. For each class of textural characteristic, several food samples were selected to represent a wide range of intensity of the characteristic. They were then judged by a group of specially trained panelists, and a rating scale for each characteristic was thus produced. The same foods were measured mechanically, using the texturometer, for the desired characteristics. The two results were then correlated. They obtained highly significant correlations in all cases. Szczesniak (1966) stated that the standard rating scales possess three important features. They serve as reference standards for the panel, thus facilitate quantification in absolute rather than relative terms; they can be expanded in any desired range to allow for greater precision in quantifying reasonably similar products; and they can be used to establish a basic correlation between objective and sensory evaluation. The method does have drawbacks in that the reference materials she chose are commercial products, which may change over a long period or may become unavailable through changes in distribution and demand patterns.

Brennan et al. (1970) used the General Foods Texturometer to study various parameters of food texture and found that hardness was the only characteristic measured by

the texturometer that correlated very strongly with sensory evaluation. They suggested that some modifications be made to the texturometer and that a somewhat different interpretation of the results was necessary to make the instrument more efficient in measuring the other characteristics.

The General Foods Texturometer is a complex, versatile and relatively expensive instrument which is more suitable for research than for routine testing of a limited range of textural parameters. It, and other versatile instruments, are particularly useful in determining the relative importance of various textural characteristics for a wide range of types of food. However, simpler and less expensive instruments such as the Warner-Bratzler shear press (for tenderness of meat), various penetrometers (for hardness or firmness of fats, fruits and vegetables etc.) have been developed for use in routine quality control work. As yet there is no simple instrument available which is suitable for measurement of either the individual textural characteristics of mashed potatoes or some relevant combination of characteristics which correlates well with consumer preference.

SECTION B. EXPERIMENTAL

I. ANALYSIS OF PECTIC SUBSTANCES IN RAW, AND COOKED POTATOES, AND POTATO GRANULES

1. Methodology

Analysis of pectic substances generally involves extraction, isolation, purification, and quantitative analysis. The extraction method depends largely on the purpose of the analysis, whether total pectic substances or their various fractions are to be determined. If total pectic substances are desired, it is possible to use a relatively drastic extraction conditions such as heating the material in a solution of calcium chelating agent, e.g. Calgon, at low pH to solubilize all the pectic substances (McCready, 1970). If, however, the pectic substances are to be fractionated into water-soluble, Calgon-soluble, and HCl-soluble portions, then milder methods such as that used by Bettelheim and Sterling (1955) may be employed.

Isolation and purification may or may not be necessary, depending on the methods of determination which may be:

i. weight of alcohol precipitate,

ii. titration of acid carboxyls plus saponification of methyl esters,

iii. weight of calcium pectate,

iv. decarboxylation by heating in concentrated mineral acids,

v. optical rotation, and

vi. colorimetric method.

Methods that require weighing of the final results such as that in i. and iii. normally require isolation and purification of the extract. Each of these methods has its disadvantages leading, sometimes, to wide variation of results. The inconsistency of the nature of pectic substances from different sources also contributes to this variation. For simplicity of determination, however, colorimetric methods are preferred. One of the most widely used is the sulfuric acid-carbazole reaction method. The method depends on the reaction between uronic acid, sulfuric acid and carbazole to produce 5-formylpyroracemic acid which gives distinct pink coloration the in tensity of which can be measured at 520 nm. McCready (1970) adequately reviewed the development and nature of this method.

2. Starch interference with carbazole reaction

McComb and McCready (1952) found that uronic acids derived from sugars such as arabinose, fructose, glucose, and some organic acids other than galacturonic acid interfere with the color development in the carbazole reaction. Potter and McComb (1957) reported definite

interference of gelatinized starch with the carbazole reaction for uronide content determination of pectic substances in cooked and processed potatoes. They recommended removal of the starch prior to the determination. A similar problem was experienced in the present studies using the carbazole method to determine water-soluble and Calgon-soluble pectic substances in raw, cooked, and processed potatoes. An attempt was thus made to modify the method to obtain more reliable results.

3. Modification of the carbazole method

The main object of the present study was to follow the changes in the water-soluble fraction of the pectic substances induced by cooking, as it is this fraction that partially determines the success in separation of the cooked potato cells during mashing and, to a lesser extent, during granulation. Thus it was thought not necessary to determine the absolute total amounts of the pectic substances in potato tissue. Instead, only two fractions, i.e. water-soluble and Calgon-soluble, were extracted and quantitated. The combined quantity of these two fractions was then designated as an "apparent total".

As mentioned above, starch interference is the major difficulty in the colorimetric determination of the pectic substances in potato tissue. Bettelheim and Sterling (1955) used α- and β-amylase to hydrolyse the starch prior

to the precipitation of the extracted pectic substances. This, however, is not thought suitable for the carbazole method as the products of the hydrolysis, which are monosaccharides, also interfere with the carbazcle reactions (McComb and McCready, 1952). To get rid of these sugars by precipitating the pectic substances in ethanol and redissolving them in water prior to the color development will not only result in more complicated extraction and precipitation methods which are subject to additional error, but also in the risk of having some residue of the alcohol and sugars left over in the final redissolved pectic substances solution to interfere with the color development.

In this study, twc approaches were used simultaneously to correct or reduce the starch interference.

a. Reduction of the amounts of starch in the extract to minimum. This was accomplished by:

i. In raw potatoes, fixing of the sample in boiling ethanol, the method employed by Bettelheim and Sterling (1955), was avoided as heat will at least partially gelatinize the starch, rendering it more soluble in water. Instead, the potatc sample was macerated in ethanol at room temperature or lower, then extracted with 0.1% sodium bisulfite solution. Sodium bisulfite was added to the extracting water to retard any monophenolase activities that may take place in the raw tissue. Excessive maceration of the tissue was alsc avoided by using Waring blendor at low

speed and using higher proportion of alcohol to potato tissue. Subsequent extractions were done at either room temperature or lower to reduce the swelling and dissolution of starch.

ii. In cooked potatoes, the potatoes were first mashed hot to avoid excessive disruption of the potato cells. The mash was then frozen in an air-blast freezer and thawed to room temperature or lower to further retrograde the starch gel, rendering it less soluble in water. A sample was then taken and subsequent analysis proceeded as in i. except that no further maceration was required, and that sodium bisulfite was not added to the extracting water.

iii. In potato granules, the extractions were performed directly on the sample, at room temperature or lower to reduce the swelling and dissolution of starch, without further treatment.

b. Starch-carbazole correction curve.

As it is not possible to entirely avoid some amounts of soluble starch in the extracts, a correction curve for the starch interference must be produced so that an additional color intensity of the carbazole reaction due to the starch can be appropriately subtracted from the total intensity.

4. Material and method

Materials:

Netted Gem potatoes, S.G. 1.095.

Potato starch. Sigma Chemical Co., St. Louis, Missouri.

Ethyl alcohol, purified.

Carbazole. J.T. Baker Chemical Co., Phillipsburg, N.J.

Sulfuric acid, reagent grade, concentrated.

Galacturonic acid monohydrate, reagent grade. Eastman Organic Chemicals Distillation Product Industries, Rochester, N.Y.

Sodium hydroxide, reagent grade.

Sodium hexametaphosphate (Calgon). Calgon Interamerican Corp., Consumer Division, Toronto.

Iodine, resublimed. Fisher Scientific Co., Fair Lawn, N.J.

Potassium iodide, granular. Fisher Scientific Co. Waring Blendor.

KitchenAid mixer. The Hobart Mfg., Co. Ltd., Troy, Ohio.

Sorvall Superspeed Centrifuge. Ivan Sorvall Inc., Newtown Conn.

Corning Magnetic Stirrer.

Spectronic 20. Bausch and Lomb Inc., Rochester, N.Y.

Methods:

a. Correction curve for starch interference

The potato starch gels of 0.036% and 0.1% (w/v) were prepared by bringing an appropriate amount of potato starch in distilled water to boil on the Corning hot plate stirrer. The concentrations of the gel were arbitrarily chosen to represent low and high starch concentrations which may be experienced in pectic substances extracts.

A D-galacturonic acid solution of 0.05% (w/v) concentration (the concentration chosen was found to be within the range normally encountered in the extracts from potatoes) was also prepared by dissolving an appropriate amount of the acid in distilled water. The solution was relatively stable only for a few days in a dark, cool place.

Standard iodine sclution was prepared according to Williams and Fegol (1969).

For low potato starch concentration, 8 incubation tubes (30 ml) with screw caps were set up for eight combinations of 0.036% starch gel, 0.05% D-galacturonic acid, and distilled water as shown in Table 2.

For high potato starch concentration, 13 incubation tubes (30 ml) were set up for the combinations of 0.1% starch gel, 0.05% D-galacturonic acid, and distilled

Table 2. Carbazole values contributed by gelatinized potato starch at low concentrations.

Tube No.	1	2	3	4	5	6	7	8
ml Potato starch gel (0.036%)	20	18	16	14	12	0	0	10
ml D-galacturonic acid (0.05%)	0	2	4	6	8	10	20	0
ml Distilled water	0	0	0	0	0	10	0	10
Blue value	1.05	0.94	0.855	0.73	0.64	0	0	0.50
Carbazole value	0.016	0.043	0.061	0.088	0.115	0.129	0.258	0.008

Table 3. Carbazole values contributed by gelatinized potato starch at high concentrations.

Tube No.	1	2	3	4	5	6	6	8	9	10	11	12	13
ml Potato starch gel (0.1%)	20	18	16	14	12	10	16	10	8	0	0	0	0
ml D-galacturonic acid (0.05%)	0	2	4	6	8	10	0	0	0	6	10	14	20
ml Distilled water	0	0	0	0	0	0	4	10	16	14	10	6	0
Blue value	2.52	2.40	1.92	1.72	1.49	1.24	1.96	1.27	0.48	0	0	0	0
Carbazole value	0.11	0.0785	0.0965	0.107	0.129	0.1275	0.061	0.0315	0.009	0.0598	0.088	0.1385	0.199

water as shown in Table 3.

To determine the Blue Value Index (BVI) of the mixtures, 2.5 ml of the mixture was mixed thoroughly with 7.5 ml distilled water and heated in boiling water for 5-10 minutes. The heating was necessary to prevent the floculation of the starch iodine complex when iodine solution was added to the mixture. After heating, the mixture was cooled down to about room temperature before 0.2 ml standard iodine solution was added and thoroughly mixed. The blue value was then measured using the Spectronic 20 at 640 nm.

For carbazole value determination, 2 ml of the original mixture (starch gel, D-galacturonic acid, and water) was hydrolysed in 30 ml of 0.05N NaOH for 30 minutes. The analysis proceeded according to the method described by McComb and McCready (1952).

The carbazole values of the mixture as well as those of pure starch gel and pure D-galacturonic acid were plotted against their concentrations (Figures 4 and 5). This was to determine whether the carbazole value increased linearly with the increase in the concentrations of both starch and D-galacturonic acid, in order to determine the usefulness and reliability of the correction curve.

The Blue Value Indices of pure starch gel were then plotted against their carbazole counterparts, and the

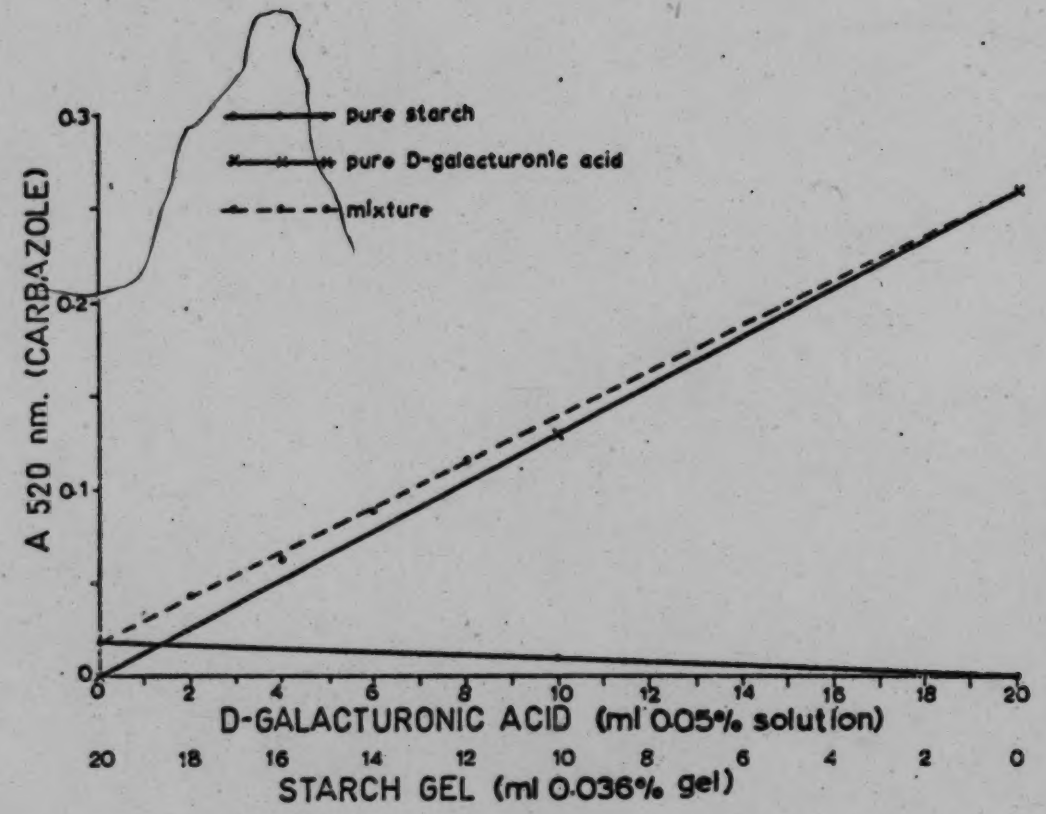


Figure 4. Effect of low concentrations of starch on carbazole values.

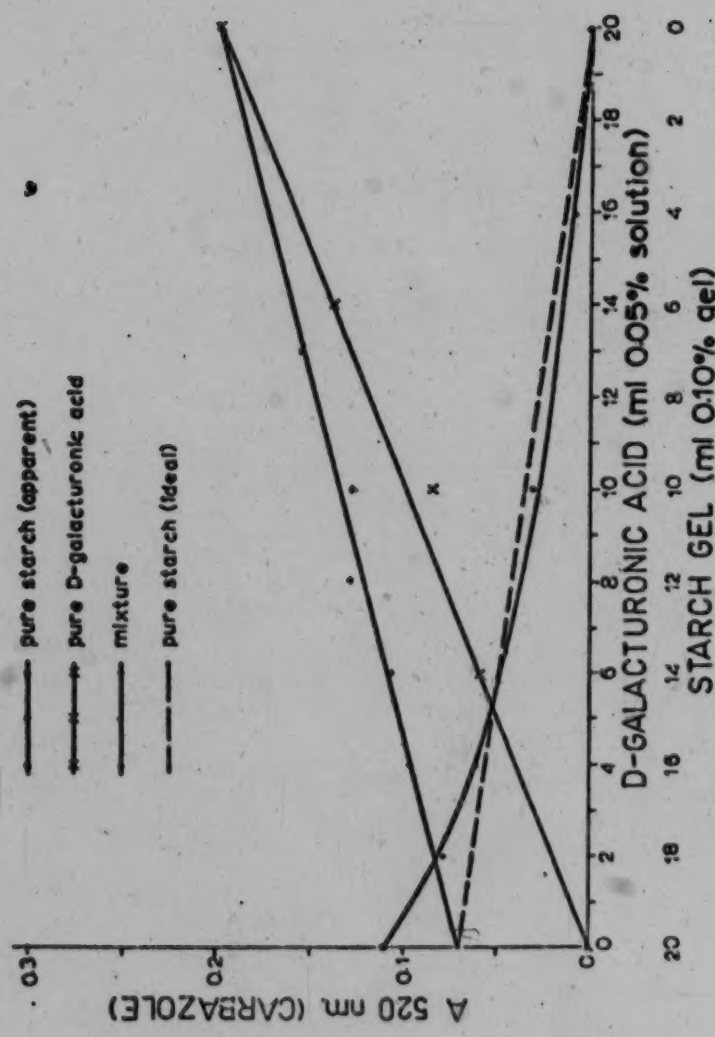


Figure 5. Effect of high concentrations of starch on carbazole values.

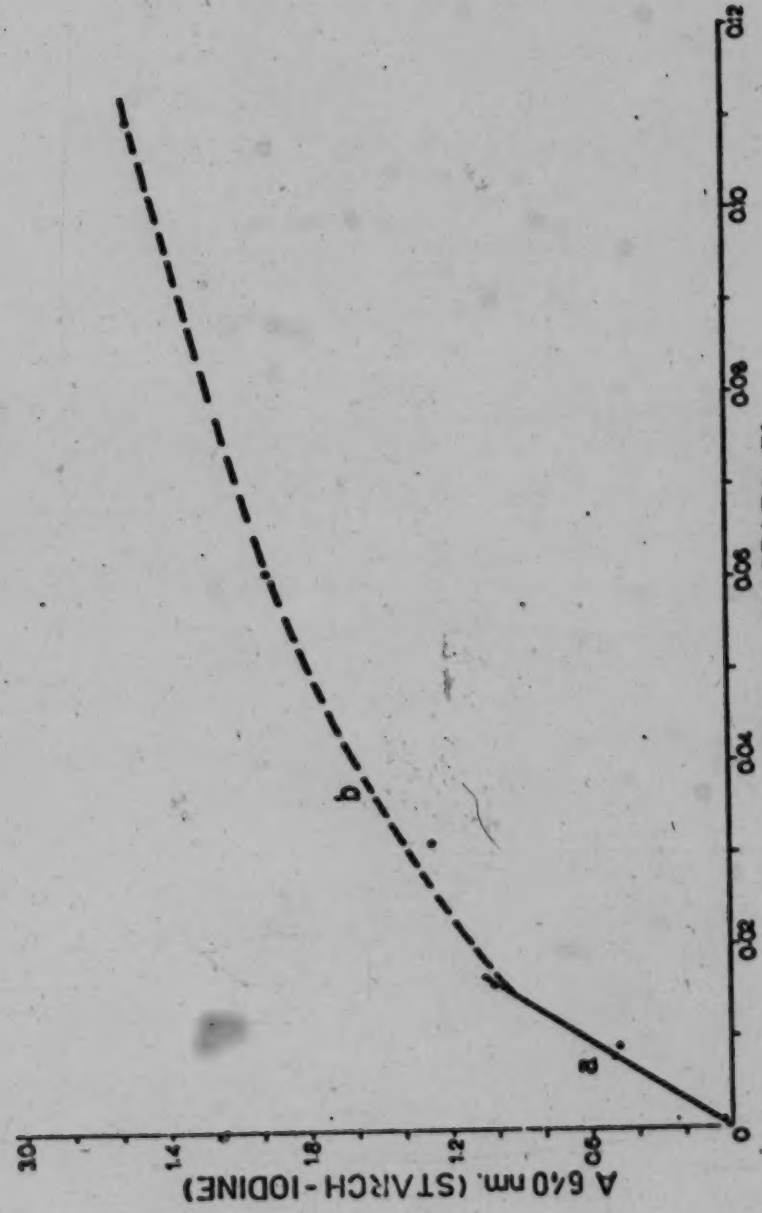


Figure 6. Correction curve for starch interference in carbazole reaction.

correction curve for starch interference was thus produced (Figure 6). Only the linear portion of the curve was used for the correction in the experiments.

b. Raw potatoes

The selected potato tuber was peeled, washed, and cut into small pieces of a few cu mm size. The pieces were mixed well and two 5 gm samples were taken.

Moisture content of the raw potatoes was determined in hot air oven at 105°C for 24 hours.

The samples taken were immediately macerated in 100 ml of 95% EtOH in a Waring Blendor at low speed for 1 minute. The macerated samples were left stand in room temperature for 30 minutes with occasional stirring, then filtered through Whatman No. 4 filter paper. The residues were washed twice with 75% EtOH (v/v). The outline of the subsequent extractions is shown in Figure 7.

c. Cooked potatoes

The potatoes were peeled, sliced, washed free of surface starch granules and steam-cooked at atmospheric pressure for 35 minutes. The cooked potatoes were then mashed immediately after cooking in the KitchenAid mixer with a flat beater at the speed setting of 6 for 1 1/2 minutes. The mash was then frozen in an air blast freezer at -18°F and thawed in room atmosphere. The moisture content of

the frozen and thawed potatoes was determined. Two 5 gm samples were then taken for the pectic substances analysis.

A 100 ml of 95% EtOH was measured into each of the samples. They were then left in room temperature for 30 minutes with occasional stirring, then filtered through Whatman No. 4 filter paper. The residues were washed twice with 75% EtOH, and further extractions proceeded as outlined in Figure 7.

d. Potato granules

Two 5 gm samples of the potato granules were taken. The moisture content of the granules was determined. 100 ml of 95% EtOH was added to the samples and the extraction proceeded as in c.

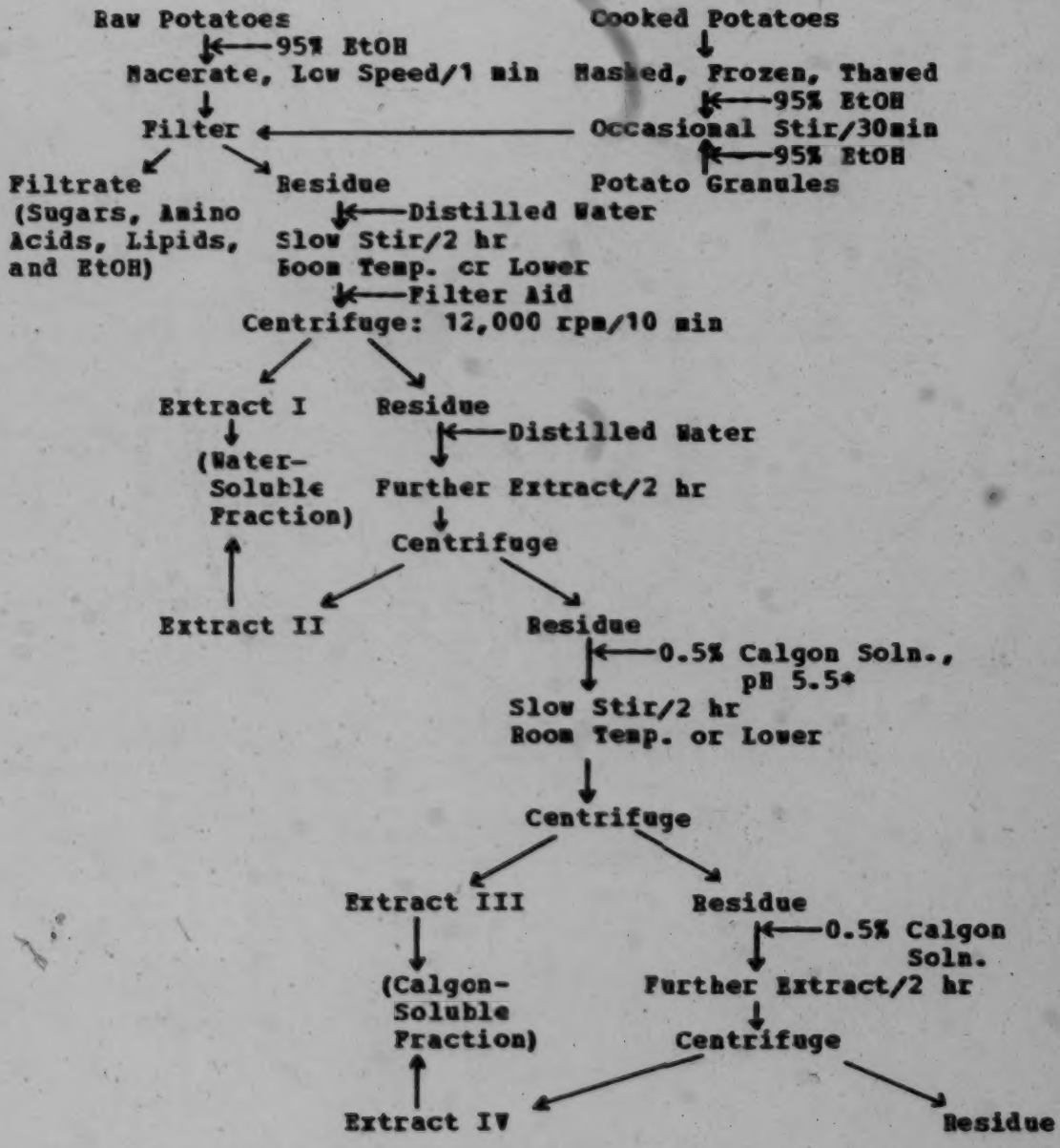
The uronide content in the extracts was determined using carbazole method as described by McComb and McCready (1952) the outline of which is shown in Figure 8.

For Blue Value Index determination of the extracts, 2.5 ml extract was thoroughly mixed with 7.5 ml distilled water and 0.2 ml standard iodine solution. The Blue Value Index was measured with the Spectronic 20 at 640 nm.

The carbazole values of the extracts were then obtained from the standard curve (Figure 9) and corrected for the starch interference using the correction curve

(Figure 4).

For the purpose of comparison of the uronide contents among samples of different moisture contents, the uronide values based on dry weight of the samples were also calculated. The moisture contents of the samples used in the experiments are given in Table 4.



*Prepared according to Bettelheim and Sterling (1955).

Figure 7. Flow chart for extraction of pectic substances from potatoes.

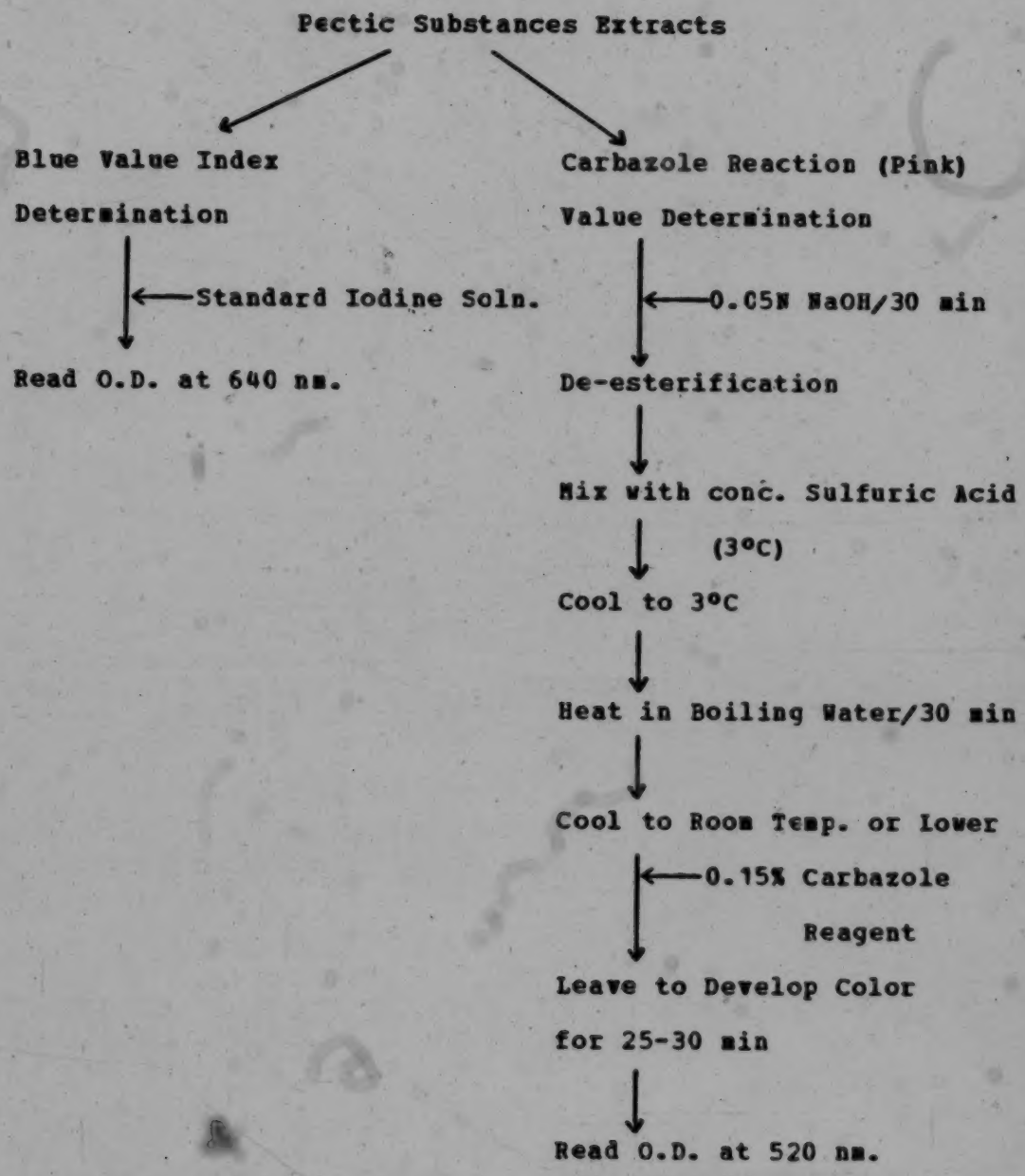

Pectic Substances Extracts
Blue Value Index Determination
Standard Iodine Soln.
Read O.D. at 640 nm.
Carbazole Reaction (Pink) Value Determination
0.05N NaOH/30 min
De-esterification
Mix with conc. Sulfuric Acid (3°C)
Cool to 3°C
Heat in Boiling Water/30 min
Cool to Room Temp. or Lower
0.15% Carbazole Reagent
Leave to Develop Color for 25-30 min
Read O.D. at 520 nm.

Figure 8. Flow chart for determination of uronide content in potato extracts.

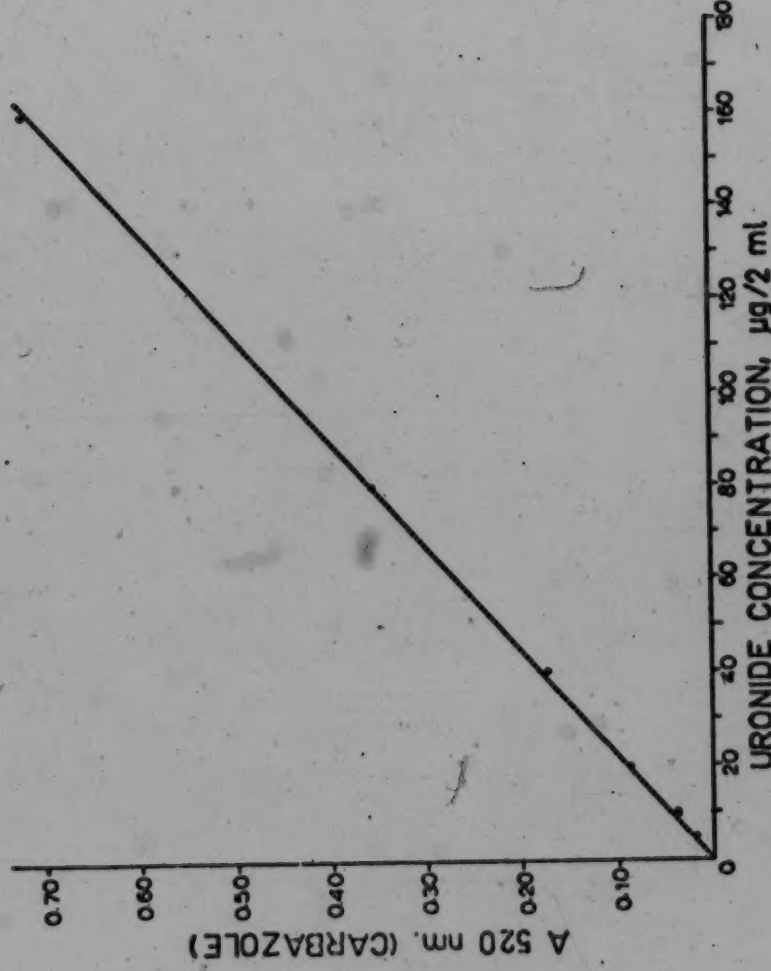


Figure 9. Standard curve for carbazole reaction.

Table 4. Moisture content of potato samples used in pectic substances determinations.

Sample	Average moisture content, % wet basis
Raw	77.33
Cooked	77.23
Granules	4.58

II. EFFECTS OF TEMPERATURE ON FIRMNESS OF COOKED POTATOES

1. Materials:

Netted Gem potatoes.

Steam bath with cover lid.

Cork borer of 0.75 in diameter.

Wire cheese cutter.

Standard iodine solution.

2. Equipment

a. Equipment for firmness measurement:

i. A force supplier which consists of a 1/2 H.P. motor driving a shaft up and down vertically through a gear box at a constant speed. The direction and speed of the motor is controlled by a speed controller Model SL14 made by Minarik Electric Co. A system of strain gauges is mounted on a platform directly under the drive-shaft.

ii. Signal amplifier: Daytronic Transducer Amplifier-Indicator Model 300D. Daytronic Corp., Dayton, Ohio.

iii. Recorder: Honeywell Electronic 19, output ranges 0.1-100 mv. Honeywell, Ft. Washington, Pa.

iv. Ott-Planimeter. Burrell Corp.,

Pittsburgh, Pa.

b. Equipment for cell count:

i. KitchenAid mixer.

ii. Leitz Wetzlar microscope (100x, 400x, and 1000x).

3. Methods:

a. Preparation of the samples for firmness measurement of whole unmashed potatoes:

Potatoes of uniform size and shape were chosen. They were peeled and their irregular surfaces were trimmed off so that they could be placed flatly on the load cell of the texturometer. The potatoes were then washed and wrapped in aluminium foil and steam-cooked for 1 1/2 hours, at atmospheric pressure to ensure uniform cooking throughout the sample. Once cooked, the potato samples were kept in a steam bath at the temperature at which the measurements were to be performed. Short duration in the steam bath between measurements was necessary to avoid further cooking if the temperatures were high. The samples were kept wrapped in the aluminium foil until measurement to avoid surface evaporation.

b. Methods of firmness measurement of intact potato tissue:

i. Puncture test. A cylindrical probe with flat surface of 0.25 in diameter was driven into the potato

sample, placed squarely on the load cell, at a constant speed of about 5.7 in/min The probe penetrated 0.7 in into the sample then the motor was reversed and the probe withdrawn from the sample at the same speed. The force vs distance (or time) was recorded simultaneously by the recorder (Figure 10). The relative area under the penetration curve, as measured with the planimeter, represents the work done by the probe to penetrate into the sample.

ii. Compression test. Cylindrical samples of 0.75 in diameter and 0.75 in height were prepared using the cork borer and the wire cheese cutter. The sample was placed squarely with a flat surface on the load cell. It was then compressed by a circular plunger with flat surface of 2 in diameter, driven down at a constant speed, until the sample was completely deformed. The force vs distance (or time) was recorded on the recorder (Figure 11). The height of the first peak which represents the breaking point of the sample was taken as the amount of force necessary to break the sample. This peak normally corresponds to the point where the sample was broken around the middle at about 45° to its flat surface. The height of the peak was then converted to gm force using a calibration curve previously constructed.

c. Trial runs:

A trial run at the sample temperature of 80°C for each type of test was first performed to determine

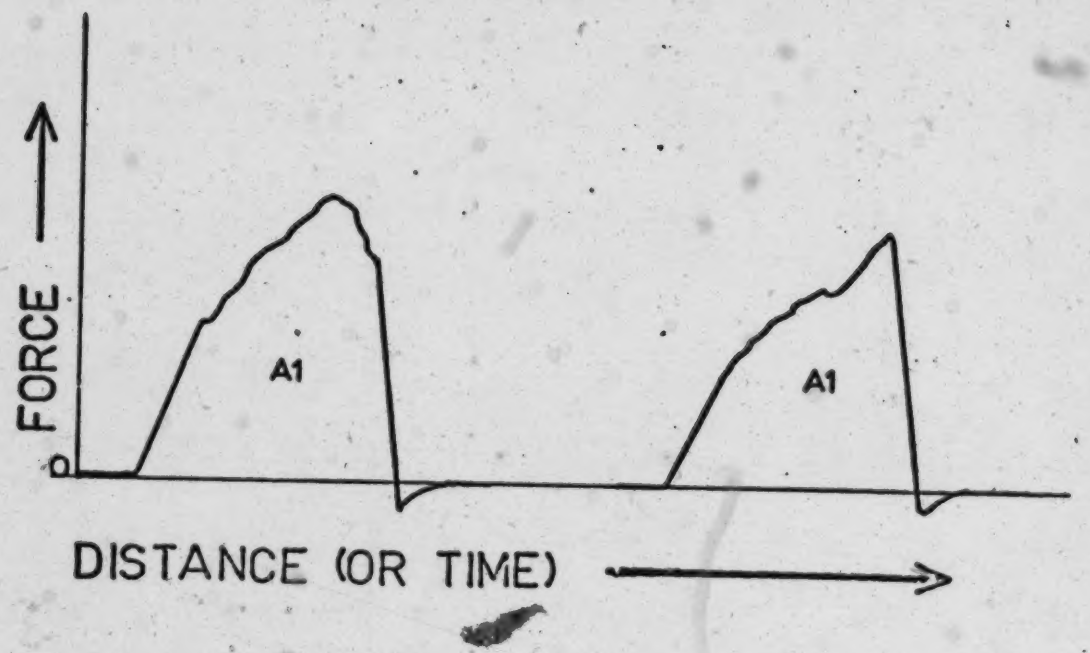


Figure 10. Typical results of the puncture test. Area A1 represents firmness.

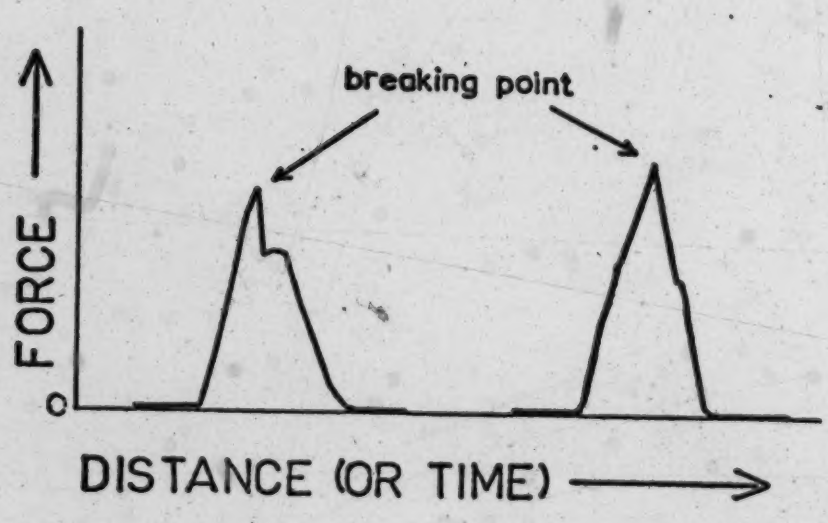


Figure 11. Typical results of the compression test.

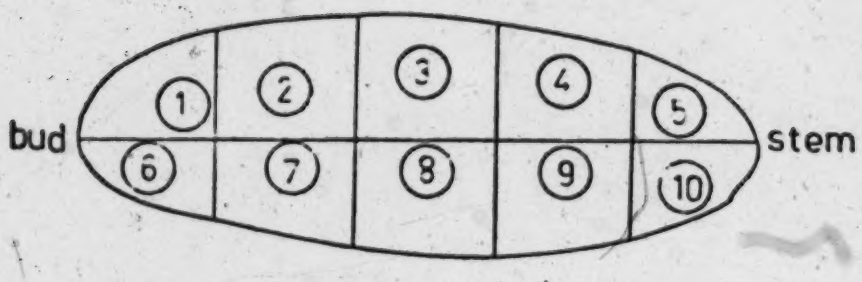


Figure 12. Section of cooked potato tuber with circles showing locations where samples were taken for compression tests.

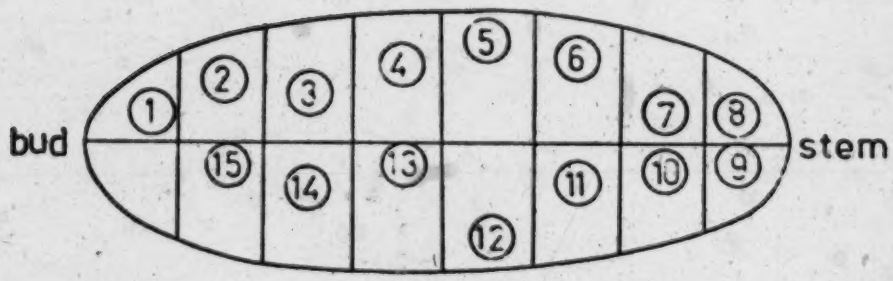


Figure 13. Section of cooked potato tuber with circles showing locations where puncture tests were performed.

the areas on a tuber where the tests should be performed so that variation in the results could be kept to minimum. This was done by dividing the tuber into several areas as shown in Figures 12 and 13, and then doing tests on each area. The areas on the tuber where the results of the measurements were most uniform to one another were then chosen for subsequent tests.

In the subsequent tests, the temperatures of the samples at which the tests were performed were arbitrarily chosen for convenience at 80°, 40°, 25°, and 10°C after cooking; and 5°, 75°, and 25°C after freezing and thawing, reheating, and recooling respectively. Four duplicates were performed for each test.

d. Cell count:

Cooked potato strips were mashed at 80°, 40°, 25°, and 10°C after cooking; and at 0° (partially thawed), 10° (completely thawed), 80° (reheated), and 25°C (recooled) after freezing, in the KitchenAid mixer with a flat beater for 45 seconds at top speed. The mashed samples were then examined under the microscope at 100x to determine the number of broken cells.

The microscopic method as describe by Reeve and Notter (1959) was employed for cell count. The method was slightly modified by adding two drops of the standard iodine solution to the sample on the slide and mixed thoroughly prior to counting. This improved the visual capability to

differentiate the broken from the intact cells as the released starch gel gives a much deeper blue stain than the intact parts of the cell. The cell boundary was also shown more clearly with the iodine staining. A total of at least 1,000 cells per slide were counted.

III. EFFECTS OF SURFACTANTS ON POTATO STARCH GEL

1. Materials:

Amylose Type 1, from potato. Sigma Chemical Co., St. Louis, Missouri.

Standard iodine solution.

Myvatex Type 3-50 (granules). Distillation Product Industries, Division of Eastman Kodak Co., Rochester, N.Y.

Myverol Type 18-40 (paste). Distillation Product Industries, Division of Eastman Kodak Co., Rochester, N.Y.

Spectronic 20. Bausch and Lomb Inc., Rochester, N.Y.

Corning Hot Plate Stirrer.

Netted Gem potatoes.

KitchenAid mixer.

2. Methods:

Two colorimetric methods, viz. that described by Mullins *et al.* (1955), and that described by Williams and Fegol (1969), were investigated for their sensitivity and reproducibility by measuring the color developed by iodine and mashed potatoes of varying amounts of broken cells.

Mullins *et al.* developed their method particularly for the determination of Blue Value Index of dehydrated mashed potatoes. In this method the solubilized starch is

extracted from the potatoes with hot water of 150°F (65.5°C). The blue color is developed by mixing the extract with a dilute iodine solution. The Blue Value Index is then obtained by measuring the intensity of the blue color at 640 nm.

The method of Williams and Pegol, on the other hand, was developed to determine the amount of damaged starch in wheat flour. In this method the starch is extracted from the damaged granules by a solution of sulfosalicylic acid in formamide-sodium sulfate solution at 122°F (50°C). The extract is then mixed with a dilute iodine solution to develop blue color. The Blue Value Index is determined at 555 nm.

Both methods were found to be comparable in sensitivity, but that by Mullins et al. was found to possess better reproducibility. Due to the nature of the extracting solution used (sulfosalicylic acid in formamide-sodium sulfate solution), the method by Williams and Pegol appears to extract some starch from the intact cells in addition to all of the starch from the broken cells. This is conceivably because the extracting solution may dissolve parts of the walls of the intact cells which are relatively thin and produce holes through which more starch is subsequently extracted. Furthermore, the method of Mullins et al. is much simpler and takes less time to execute and hence was chosen for this experiment.

a. Effects of surfactants on pure amylose:

A 500 ml suspension of 0.01% (w/v) amylose in distilled water was boiled on the Corning Hot Plate Stirrer for 25 minutes, then filtered through No. 4 Whatman filter paper. The filtrate was designated as solution I.

A 500 ml suspension of 0.1% (w/v) Myvatex in distilled water was boiled for 25 minutes on the Corning Hot Plate Stirrer and filtered through No. 4 Whatman filter paper. The filtrate was designated as solution II.

The combinations as shown in Table 5 were set up in a series of 10x100 ml flasks.

The content in the flasks was mixed well. To each flask, 1 ml of the standard iodine solution was added and thoroughly mixed.

Individual blank for each flask was used to compensate for the interference of the color development which might be caused by Myvatex. These blanks were prepared by replacing soln. I in the combinations with 25 ml distilled water.

The absorbance of the mixture in each flask was measured against its blank with the Spectronic 20 at 640 nm.

b. Effects of surfactants on starch gel in cooked, mashed potatoes:

Table 5. Combination of amylose, Myvatex, and water for the determination of iodine affinity of amylose in the presence of surfactants.

Flask No.	1	2	3	4	5	6	7	8	9	10
ml soln. I*	25	25	25	25	25	25	25	25	25	25
ml soln. II**	0	0.5	1.0	1.5	2.5	3.5	5	10	15	25
ml distilled water	25	24.5	24.0	23.5	22.5	21.5	20.0	15.0	10.0	0
Equivalent % Myvatex in the mixture	0	.001	.002	.003	.005	.007	.01	.02	.03	.05

* Soln. I is 0.01% (w/v) amylose solution.

** soln. II is 0.1% (w/v) Myvatex suspension.

The effects of Myvatex and Myverol on cooked potatoes were determined separately.

Potatoes were peeled, sliced, and washed. The washed potato strips were steam-cooked for 35 minutes. Appropriate amounts of the surfactant (up to 1% based on the cooked potato weight) was measured into the cooked potatoes. The potatoes were then mashed immediately in the KitchenAid mixer with a flat beater for 1 1/2 minutes. The broken cell count of the mashed potatoes was determined so that the number of the broken cells in each batch could be kept close to one another in order to minimize the variation in the amounts of the released starch gel.

The determination of the absorbance of the starch-iodine-surfactant complex for each sample were performed in three stages, i.e. immediately after mashing, after cooling to 42°F, and after freezing and thawing.

The method by Mullins et al. (1955) was used with slight modification, i.e. a Corning Hot Plate Stirrer was used to keep the suspension stirred at low speed and to keep the temperature relatively constant at 150°F instead of an overhead variable speed agitator. Also, 0.02N iodine solution was replaced with the standard iodine solution prepared according to Williams and Fegol (1969); and a Spectronic 20 at 640 nm. was used instead of the Klett-Summerson Photoelectric Colorimeter originally employed.

For potato granules, 0.5 gm of the dry granules was used instead of 2.5 gm as in the case of the freshly mashed potatoes. Moisture content of all samples was also determined using a hot air oven at 105°C for 24 hours.

All results are the average of two measurements and are reported as based on both original weight (wet basis) and bone dry weight (dry basis) of the samples.

IV. EFFECTS OF SURFACTANTS ON PECTIC SUBSTANCES

1. Materials:

Slow-set Genu Pectin. Food Products Ltd., Montreal.

Myvatex Type 3-50.

Myverol Type 18-40.

Corning Hot Plate Stirrer.

Brookfield Synchro-Lectric Viscometer, Model RVT. Brookfield Engineering Laboratories, Stoughton, Mass.

Mercury in glass thermometer, range -20° to 110°C, subdivision 1°C.

2. Methods:

For each set of experiments, about three litres of 1% (w/v) of the Genu Pectin in distilled water was prepared by slowly adding the pectin into continuously stirred water on a hot plate stirrer. The suspension was

brought to boil until all the pectin powder was dissolved. The gel solution was then divided up into 500 ml portions in 600 ml beakers. An appropriate amount of surfactant was weighed into each portion to make a series of 0.075-0.10% (w/v) for Myvatex, and 0.02-0.20% (w/v) for Myverol. The mixture of the pectin gel and surfactant was then brought to boil while being continuously stirred. The viscosity of the boiled mixture was then measured with the Brookfield Synchro-Lectric Viscometer using spindle No. 1 and the spindle speed of 100 rpm. Both the viscosity and the temperature of the solution at measurement were recorded. The solution was then gradually cooled down while its viscosity and temperature were being recorded at intervals.

The viscosity and temperature of a control (pectin gel with no surfactant added) were also recorded over the same range of temperature along with each set of experiments.

The viscosity and temperature of Myvatex and Myverol solutions in distilled water were also measured, using distilled water as a control.

V. ESTIMATION OF SURFACE HEAT TRANSFER COEFFICIENT IN AIR-BLAST FREEZING OF COOKED, MASHED POTATOES

1. Materials:

Netted Gem potatoes, S.G. 1.095.

Copper-constantan thermocouples.

Honeywell Electronik 19 Recorder.

Wire-mesh tray of 30 mesh size.

Air-blast freezer with air velocity of 3,000 cu ft/min, and minimum air temperature of -20°F in cold room 12x10x8 ft high.

2. Methods:

The copper-constantan thermocouple was connected directly to the recorder using ice as a reference junction. The recorded output was calibrated against a mercury in glass thermometer.

The potatoes were peeled, sliced, washed, and steam-cooked for 35 minutes. The cooked potatoes were mashed in KitchenAid mixer with a flat beater for 2 minutes at the speed setting of 6. The mashed potatoes were then packed tightly into cubic form of various dimensions ranging from 1 in to 5 in. The density of the cubes was calculated by dividing the weight of the cubes by the volume.

A thermocouple was carefully inserted into each cube from its side so that the junction was exactly at the geometrical center of the cube. The cubes were then wrapped in aluminium foil and their temperature was brought down to 32°F, using crushed ice as cooling medium.

The mashed potato cubes at 32°F were then placed on the wire-mesh tray, after they were unwrapped, and placed in the air-blast freezer. Care was taken so that the

freezing air could circulate around the cubes without obstruction. The temperature at the center of the cubes was then recorded on the Honeywell Electronik 19 Recorder.

The moisture content of the mashed potatoes was also determined in a hot-air oven at 105°C for 24 hours.

A typical recorded chart is shown in Figure 14 where:

tf = freezing point of mashed potatoes, °F.

ta = air temperature of the air-blast freezer, °F.

θ2-θ1 = time taken to freeze the center of the potato cube, hours.

Surface heat transfer coefficients were then calculated using Plank's equation:

$$\theta = \frac{\lambda\rho}{(tf-ta)} \cdot \left(\frac{Pa}{hs} + \frac{Ra^2}{k} \right), \text{ where:}$$

θ = time taken to freeze the center of a material of certain dimensions, commencing from its freezing point, hours.

λ = latent heat of the material, Btu/lb.

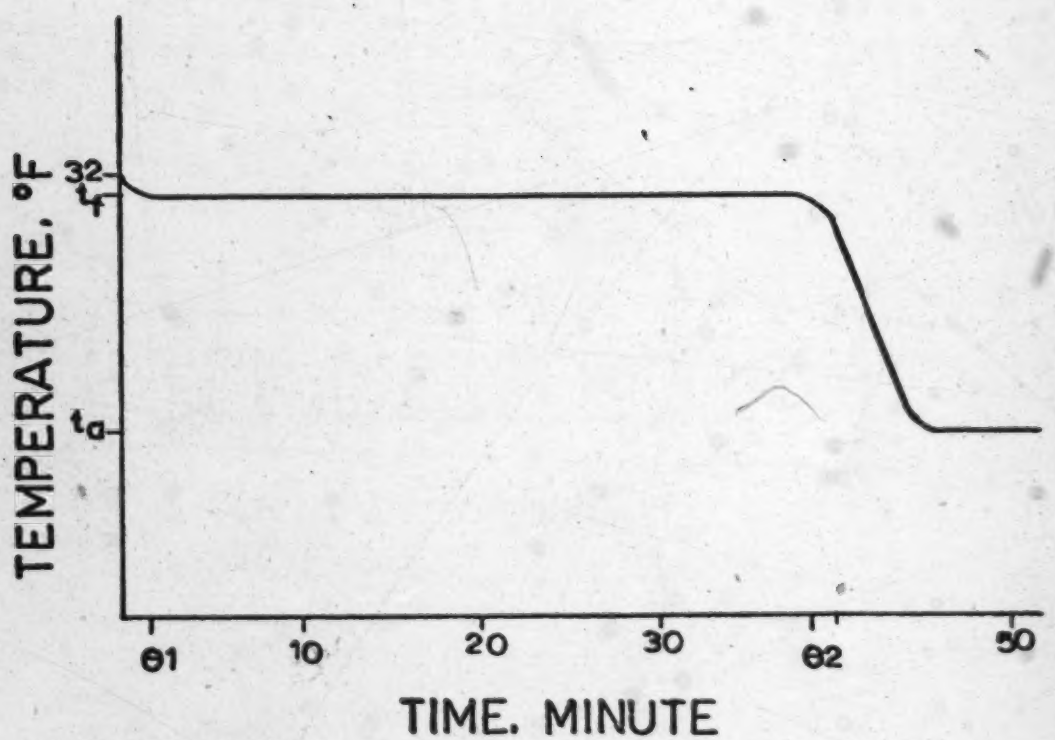


Figure 14. A typical freezing curve.

ρ = density of the material, lb/cu ft.

tf = freezing point of the material, °F.

ta= temperature of the freezing medium, °F.

P and R = coefficients obtained from the chart (Ede, 1949), based on dimensional ratios of the material. For each cube: P = 1/6, R = 1/24.

a = thickness of the material, ft.

hs = total surface heat transfer coefficient which is a combination of convection heat transfer coefficient (hc), thickness of packing material and its thermal conductivity (k), and radiation heat transfer coefficient (hr), Btu/ft² h °F.

k = thermal conductivity of the material, Btu/ft h °F.

Determinations of latent heat and thermal conductivity were not done on the batch of potatoes used in these tests. The values of these properties were calculated from the known % moisture content (p) using the equations given by Earle (1966):

$$\lambda = \frac{144p}{100} \text{ Btu/lb.}$$

$$k \text{ (below freezing point)} = \frac{1.4p}{100} + \frac{0.15}{100}(100-p) \text{ Btu/ft h °F.}$$

VI. PRE-DRYING, GRANULATION, DRYING, COOLING,

AND PRODUCT CHARACTERISTICS

1. Materials and equipment:

Netted Gem potatoes, S.G. 1.080 and 1.095.

Sodium bisulfite. Fisher Scientific Co., Fair Lawn, N.J.

Additives (see Table 19).

Hydrometer. Potato Chip Institute International, Cleveland, Ohio.

Hobart Vegetable Peeler. The Hobart Mfg. Co. Ltd., Don Mills, Ont.

Hobart Vegetable Slicer. The Hobart Mfg. Co. Ltd., Don Mills, Ont.

KitchenAid mixer. The Hobart Mfg. Co. Ltd., Troy, Ohio.

Atmospheric Steam Cooker.

Stainless steel trays.

Air-blast freezer with minimum air temperature of -20°F and air velocity of 3,000 cu ft/min

Manesty Petrie Fluid Bed Dryer model MP.10.E.. Manesty Machines Ltd., Speke, Liverpool, U.K.

Speedomax 12-point temperature recorder. Leeds and Northrup, Canada, Ltd.

Canadian Standard Sieve Series. The W.S. Tyler Company of Canada Ltd., St. Catharine, Ont.

Portable Sieve Shaker. The W.S. Tyler Company of Canada Ltd., St. Catharine, Ont.

Leitz Wetzlar Microscope. Germany.

Sling psychrometer. Taylor Instrument Companies, Rochester, N.Y.

Bendix Psychron. Bendix Environmental Science Division, Baltimore, Maryland.

"Veeder" Speedometer. The Veeder Mfg. Co., Hartford, Conn.

2. Methods:

a. Preparation of the potatoes.

The potatoes were cleaned with a dry cloth until free of dirt. The specific gravity of the potatoes was then measured with the Potato Chip Institute International hydrometer. The potatoes were then abrasive peeled in the Hobart peeler. Hand trimming of peel and dark spots was kept to minimum. The peeled potatoes were sliced to 1/2 in x 1/2 in strips in the Hobart Vegetable Slicer. The strips were washed clean of surface starch and soaked in 0.5% sodium bisulfite solution at room temperature for five minutes. They were then steam-cooked for 35 minutes. The cooked potatoes were immediately mashed in the KitchenAid mixer with a flat beater at the speed setting of 6 for two minutes, together with the additives (Table 6) which were mixed dry into the potatoes. The mashed potatoes were then spread 1/2 in thick on the stainless steel trays before being frozen in the air-blast freezer.

The frozen potatoes were completely thawed at room

Table 6. Additives used in processing of potato granules using the proposed processing technique.

Additives	% Added (Based on Weight of Potatoes)
Myvatex	0.20
Tetrasodium pyrophosphate	0.05
Butylated hydroxyanisole (BHA)	0.0005
Butylated hydroxytcluene (BHT)	0.0005
Total	0.251

temperature (approximately 70°F), without raising the temperature of the potatoes much higher than freezing point, prior to proceeding to the pre-drying step.

b. Pre-drying, granulation, drying, and cooling.

i. Modification and operation of the equipment:

The Manesty Petrie Fluid Bed Dryer (Figure 15) was modified by fitting a rotary stirrer immediately above the porous plate. The porous plate consists of a layer of wire mesh of 120 mesh size supported underneath by another layer of stronger wire mesh of 30 mesh size. The two layers are reinforced on each side by a stainless steel plate on which small holes were bored through at close intervals (5/16 in holes on 7/8 in centers (triangular pitch)). The holes of the upper plate when fitted together are in perfect alignment with those on the lower plate so that air can pass through without much obstruction. The effective area on the porous plate through which the air pass is 0.073 sq ft.

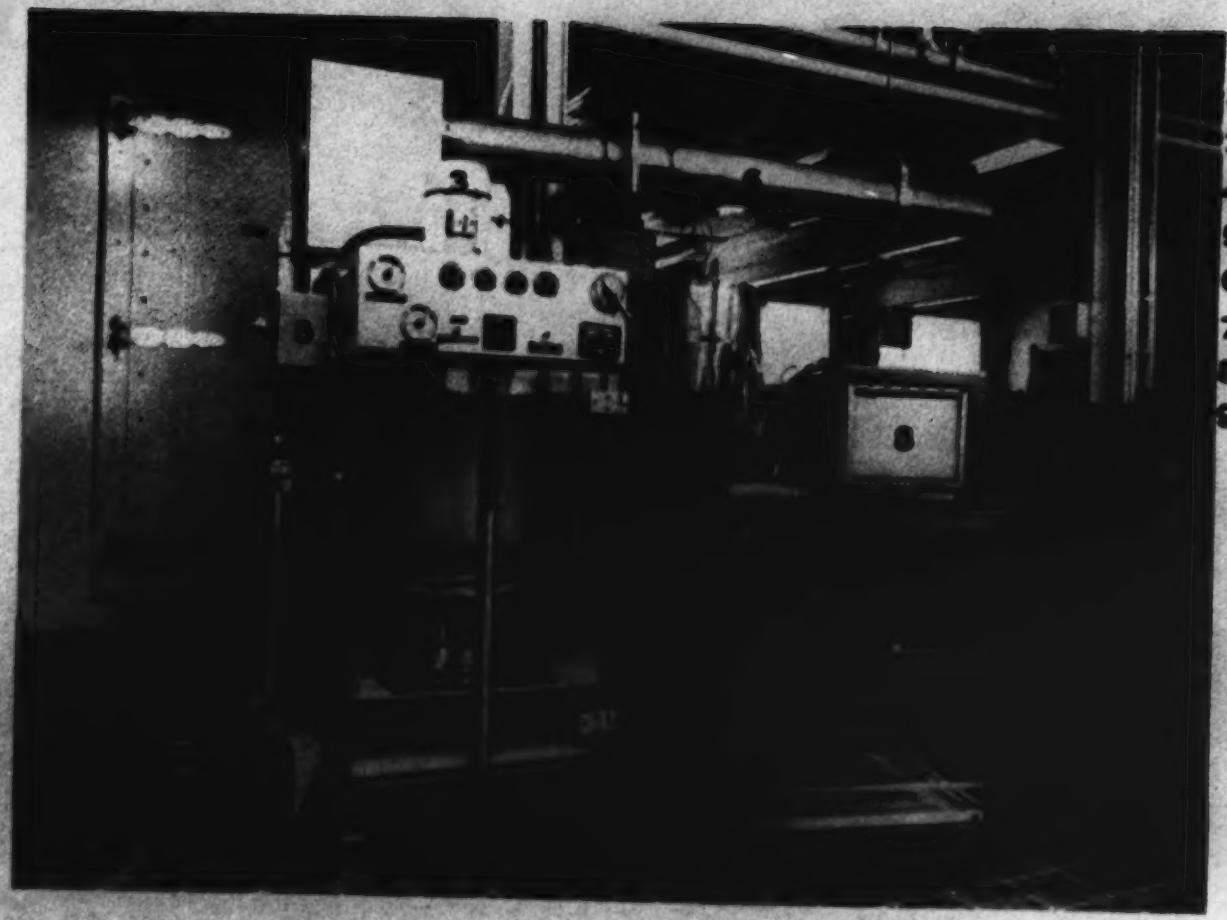
A vertical drive-shaft was fitted in the middle of the porous plate. The rotary stirrer which is made up of two aluminium arms fitted with 1/8 in diameter bent brass rods as shown in Figure 16 was fitted on to the central drive-

shaft. The clearance between the bent rod and the porous plate is approximately 0.06 in, and that between the side-arm rods and the side of the fluidizing bowl is approximately 0.1 in (Figure 17).

The central shaft is driven through a reduction gear by a 1 H.P. motor the speed of which is controlled by a variable speed motor control (Ratiotrol, Boston Gear Division, North American Rockwell, Quincy, Mass.) as shown in Figure 15.

The attachment mechanism between the nylon collecting bag and the fluidizing bowl was modified by using an aluminium ring padded with foam rubber with four metal springs holding the bag down tightly to the rim of the bowl. This is to ensure minimum leakage of the granules during drying, and for quick release of the bag when necessary.

The air inlet port on the fluid bed dryer was fitted with air-flow and temperature measuring devices (Figure 15). The orifice meter was designed to ASME standards (Bean, 1971). The air-flow pipe is an aluminium pipe with the average inside diameter of 6.370 in, with a slot five feet from the opening end into which aluminium orifice plates can be inserted. Four orifice plates were used interchangeably according to the velocity of the air flow being measured. The diameters of the orifices are 1.280, 2.557, 3.843, and 4.781 in respectively. The air flow was measured by measuring the difference in the air



1 fluidizing bowl
2 collecting bag
3 fan motor
4 stirrer motor
5 Ratiotrol
6 air-flow pipe
7 orifice slide
8 Speedomax recorder
9 manometer

Figure 15. Hanesty Petrie Fluid Bed dryer with orifice meter and temperature recorder.

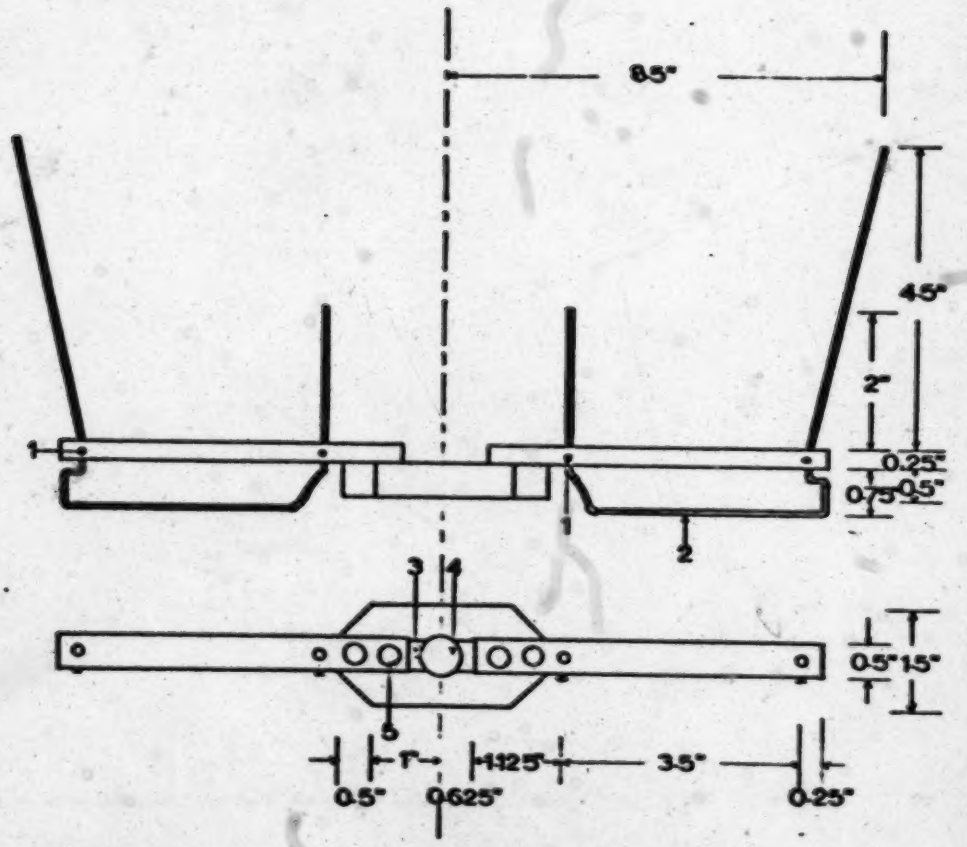
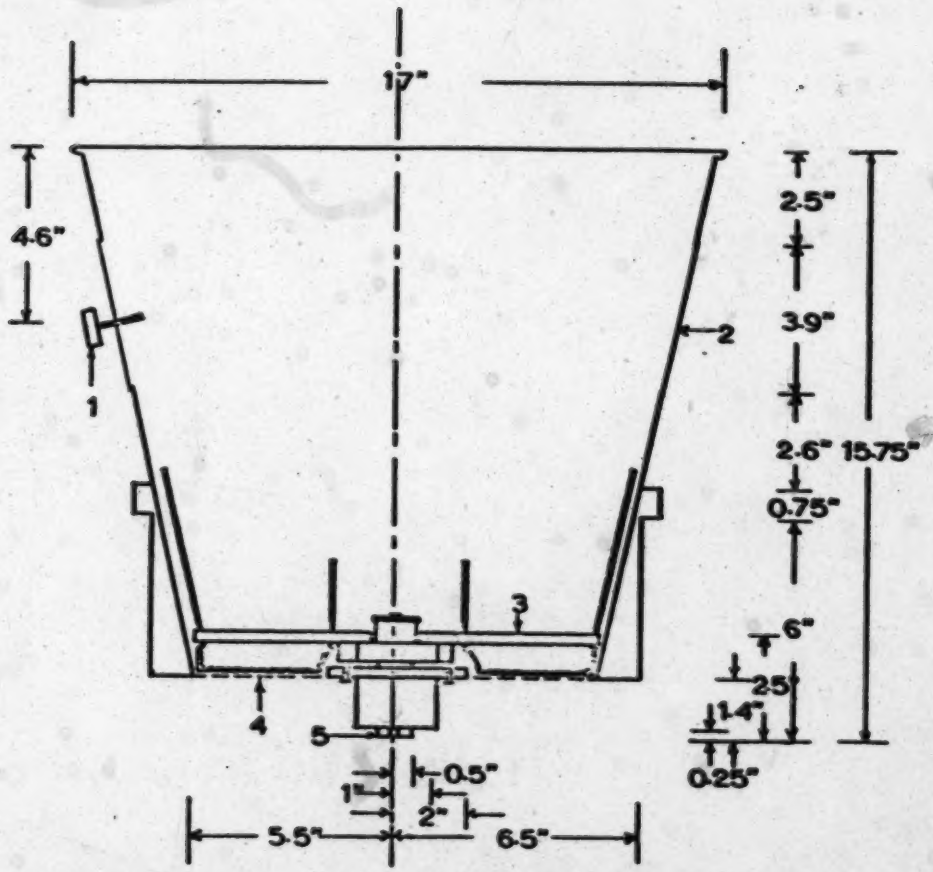


Figure 16. Stirrer for the fluid bed dryer.



1 thermometer
2 observation window
3 stirrer
4 porous plate
5 drive shaft

Figure 17. Fluidizing bowl fitted with the stirrer.

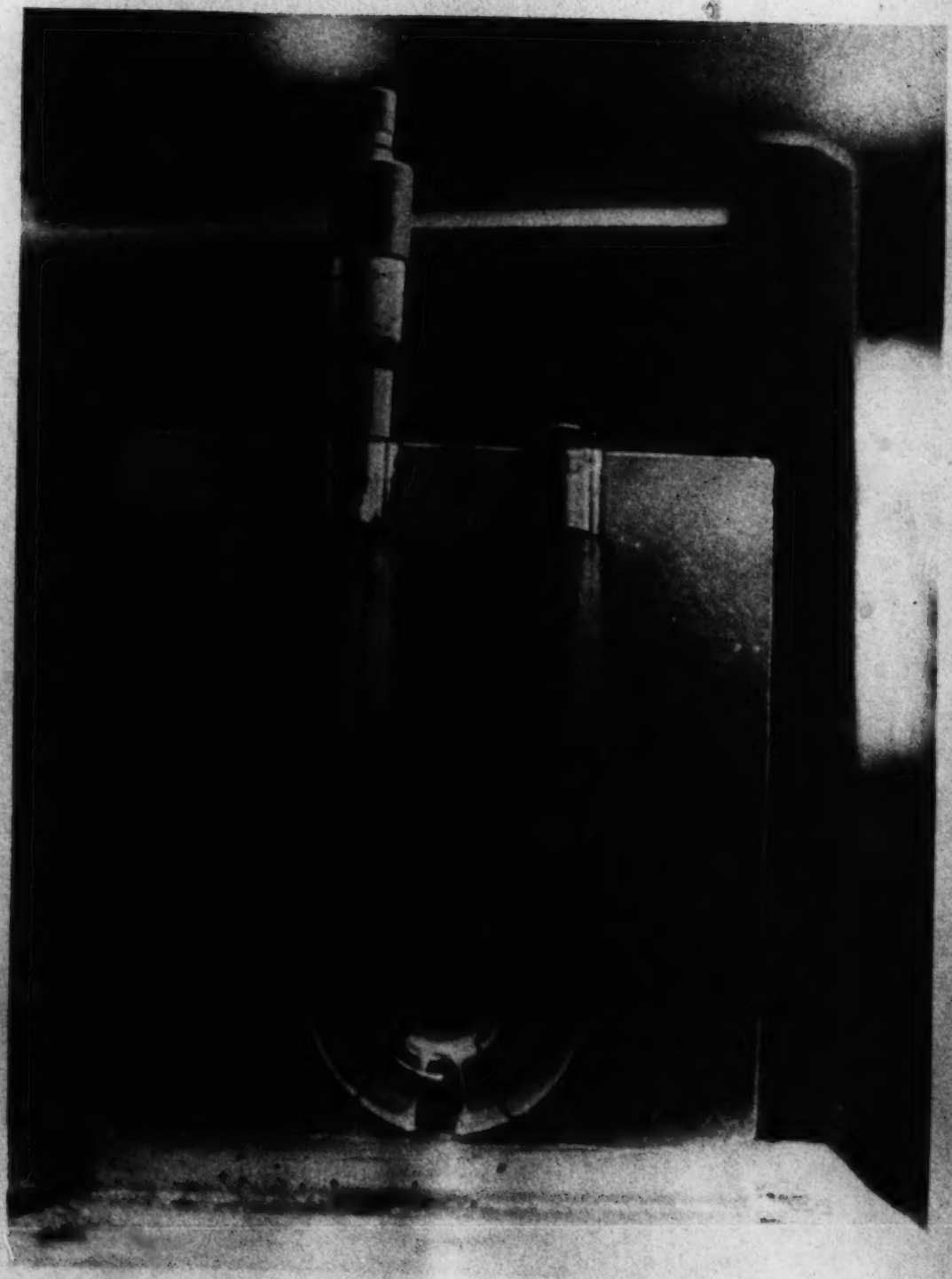


Figure 18. Manometer for orifice meter.

pressures in front and behind the orifice, using a glass manometer as shown in Figure 18.

On the downstream arm of the manometer, a micrometer with the precision of 0.001 in was fitted. The manometer was filled with distilled water to a specific level where the micrometer was zeroed. The manometer was connected to the upstream and downstream pressure tappings of the orifice meter with plastic tubes.

A wet bulb thermocouple (wet-wick covered), and a dry bulb thermocouple (bare) were inserted into the air-flow pipe 9 and 7 inches from the opening end respectively. Another two thermocouples, one under the porous plate and another in the center of the upper rim of the fluidizing bowl were also fitted. When under operation, the pressure difference of the air flow was recorded manually at appropriate intervals while the temperatures of the wet bulb, dry bulb, drying air, and the moist air coming through the bed were automatically and simultaneously recorded on the Speedomax temperature recorder. The wet bulb and dry bulb temperatures were checked against those obtained with the Sling psychrometer, and the Bendix Psychron at regular intervals.

The speed settings on the Ratiotrol for the stirrer were calibrated using the "Veeder" speedometer to measure the speed of the stirrer both with and without

potato load during pre-drying and granulation steps.

The air velocity was calculated using the following equation (Bean, 1971):

$$m = 358.93\left(\frac{CYd^2Fa}{\sqrt{1-\beta^2}}\right)\sqrt{\rho hw}$$

where: m = mass flow rate, lb/hr.

C = discharge coefficient of the orifice.

Y = expansion factor.

d = orifice diameter, in.

Fa = thermal expansion factor.

ρ = density of the air, lb/cu ft.

hw = differential pressure, in water.

β = ratio of diameters, d/D.

D = diameter of the pipe, in.

Y was calculated from the following equation:

$$Y = 1 - \frac{1-r}{k}\left(0.41+0.35\beta^4\right)$$

where: 1-r = hw

k = ratio of specific heat of ideal gas.

It was found that the minimum value of Y involved in the subsequent calculations was only 0.999, so the term was omitted.

Fa = 1 for metals near room temperature.

The values of C were interpolated from the tables in Bean (1971).

p was calculated from $\frac{1+H}{v}$, where:

H = absolute humidity of the air, lb water/lb dry air.

v = specific volume of the air, cu ft/lb dry air, corrected for altitude and temperature by the method outlined in Perry (1963).

The absolute humidity of the air entering the dryer is determined from the inlet wet and dry bulb temperatures, and this with the temperature of the air below the bed define the condition of the air at this point.

The Joule-Thompson effect is negligible for the small pressure drops through the bed, and hence cooling of the air is mostly due to evaporation of moisture from the bed. (Some cooling (or heating) of the air due to heating (or cooling) of the bed occurs when the bed temperature is changing rapidly (e.g. at beginning of run or during cooling of dry granules), but is not important during most of the drying period).

When the sensible heat effects are negligible the absolute humidity of the air above the bed is determined using the adiabatic cooling lines on the psychrometric

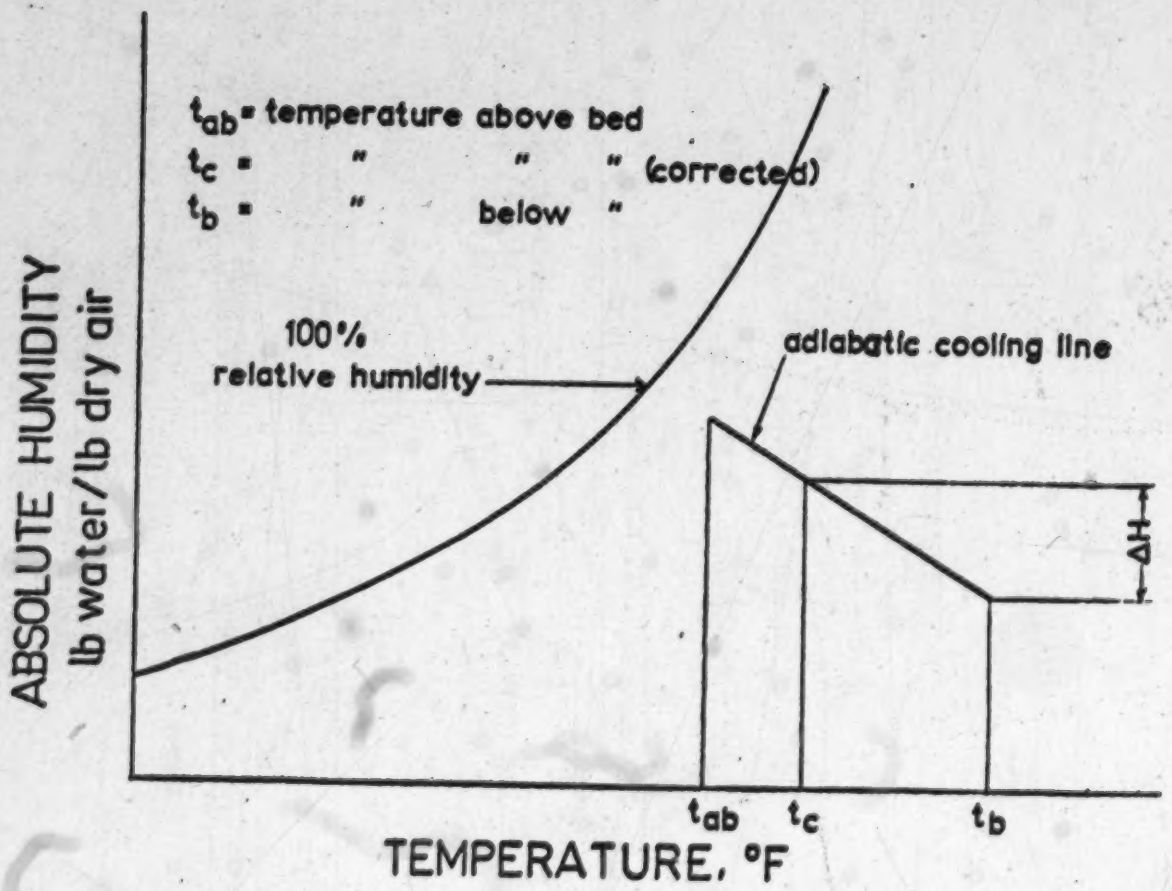


Figure 19. Psychrometric chart with typical drying rate calculation.

chart, as shown in Figure 19, where ΔH (lb moisture/lb dry air) is the increase in absolute humidity of the air. The drying rate of the bed, W (lb/hr), is then given by the equation:

$$W = \Delta H.m$$

where m is mass flow rate of air in lb/hr.

For those periods when the sensible heat effects are not negligible (e.g. during granulation) an appropriate correction was made to the temperature of the air above the bed as follows:

The temperature of the bed is assumed to be approximately equal to the temperature of the air above the bed. The rate of heat gain by the bed ($= (Mw.cw + Ms.cs).dT/d\theta$) is equal to the rate of loss of heat by the air stream ($= m.c.\Delta T$), where:

Mw = mass of water in bed
Ms = mass of solids in bed
cw = specific heat of water
cs = specific heat of solids
$dT/d\theta$ = rate of heating of bed, and
c = specific heat of air (dry basis).

This leads to an approximate correction (ΔT) for temperature above bed i.e.

$$\Delta T = (4/\pi)(Mw + 0.2Ms)(dT/d\theta)$$

The temperature of the air above the bed corrected for sensible heat effect (Tc) is then given by

$$Tc = Tab + \Delta T$$

where

Tab = measured temperature of air above the bed.

The drying rates calculated from the air flow and temperature measurements were used to calculate moisture contents of the load at several points during the runs, by integrating the rate of loss of moisture from the bed with respect to time. The superficial air velocity (ft/min) was calculated based on the cross sectional area of the bottom of the bed.

ii. Pre-drying:

The drying chamber of the fluid bed dryer was pre-heated to about 155°-175°F, and the drying air temperature was set at about 200°F.

The thawed potatoes (about 50°F) of known moisture content were charged into the fluidizing bowl. The bowl was then covered tightly with the nylon collecting bag. The drying chamber was closed, the air flow was set at maximum and the stirrer speed was set low at 20 rpm. The temperature recorder was started simultaneously, and the manometer reading was recorded and checked for any change at regular

intervals.

As the potatoes were being dried they became more and more fluidized. When all the potatoes were fully fluidized under the maximum air flow, which normally took 20-40 minutes depending on the weight of the load and its moisture content, the heaters were turned off. Small samples of the potatoes were quickly taken by temporarily opening up the drying chamber and the collecting bag. Moisture content of the samples were then determined in a hot air oven at 105°C for 24 hours.

iii. Granulation:

When the drying air temperature was dropped down to about 105°F, the air velocity was reduced to almost minimum and the stirrer speed was increased to about 480-500rpm. At this stage, the moisture content of the potatoes were usually within the critical range of 42-35% at which level the potato cells are most resistant to mechanical forces, and hence stronger force, i.e. higher stirrer speed, can be applied to separate them to fine powder without excessive cell damage. The stirrer speed was maintained during granulation while the air flow was gradually increased. The granulation takes about 4-10 minutes to complete towards the end of which the air flow was increased to about 250 ft/min under which the granulated potatoes should be fully suspended in the air stream.

About one minute before the end of the granulation period the heaters were again turned on. At the end of granulation the stirrer was stopped, and small samples of potatoes were again taken for moisture content determination.

iv. Drying:

After the granulation, the drying temperature was raised to about 175°-200°F. The air flow was set to maximum at the beginning of the drying period, but was gradually reduced after about five minutes of drying to avoid the cell damage due to the abrasion of the granules in the air stream. The drying normally takes about 10-15 minutes at the end of which the air flow was reduced to a minimum.

v. Cooling:

To avoid scorching and undesirable chemical changes due to high product temperature, a cooling period after drying is necessary. At the end of the drying period the heaters were turned off and the air flow was maintained at the low flow rate. The product temperature was reduced gradually to about room temperature after 5-10 minutes.

c. Product characteristics.

i. Size analysis and bulk density measurement:

The cooled product was sieved through a series of 16, 32, and 60 mesh Canadian Standard sieves which were mechanically shaken by the Portable Sieve Shaker for 10 minutes. The granules retained on each sieve were weighed and the weight percentages calculated. Those passed through 60 mesh sieve were taken as product. Those retained on the 32 and 60 mesh sieves were recycled back to the predrying step and mixed with the freshly thawed potatoes of the next run. The coarsest fraction which was retained on the 16 mesh sieve, normally accounted for about 1% of the total output, and was discarded.

The bulk density of the product was measured by filling the granules into a 250 ml graduated cylinder up to the 200 ml mark while gently tapping the cylinder (against the floor) until there is no further packing of the granules. The 200 ml granules were then weighed and the bulk density was calculated in gm/cc.

ii. Moisture content:

Moisture content of the product was determined using the hot air oven at 105°C for 24 hours (i.e. until the sample weight was constant).

iii. Broken cells:

Number of broken cells of the product was counted using the method described in Section B: II., 3., d..

VII. TEXTURE PANEL TESTS

1. Materials:

Four dehydrated mashed potato samples being tested were:

i. Experimental granules I (Ex. I), a typical product obtained from the process under investigation.
ii. Experimental granules II (Ex. II), a specially processed product of very gluey texture.
iii. Commercial I (Com. I), commercial potato granules obtained from a local supermarket.
iv. Commercial II (Com. II), commercial potato flakes obtained from a local supermarket.
Netted Gem potatoes, S.G. 1.095.
KitchenAid mixer.

2. Methods:

The control sample was prepared, using Netted Gem potatoes, by cooking the peeled, trimmed, sliced, and washed potatoes in a steam cooker for 35 minutes. The cooked potatoes were then mashed in the KitchenAid mixer with a flat beater at the speed setting of 6 for 1 1/2 minutes.

Salt was also added to the potatoes during mashing at the rate of 0.4% based on the cooked potato weight. The mashed potatoes were transferred to a stainless steel bowl, covered with aluminium foil, and kept warm in a kitchen oven until ready for testing.

The four dehydrated samples were first tested for their consistency on reconstitution. This was done by reconstituting each sample with varying amounts of boiling water. The samples were then judged by three judges, chosen from laboratory personnel, for their consistency as compared to that of the control sample. The term consistency used here was referred largely to the firmness of the product texture as felt in the mouth.

Once the ratio of product to boiling water for each sample was established, it was used throughout the testing.

For the test panel, the products were reconstituted by measuring an appropriate amount of boiling water into a bowl. The weighed product with 0.4% salt, based on combined weight of the product and water, was gradually poured into the water while the mixture was being stirred slowly with a fork. After all of the dry product was poured in, the mixture was thoroughly mixed at a moderate speed with a fork. The reconstituted products were then covered with aluminium foil and kept warm in the oven until ready for testing.

Two sets of test panel were conducted. Each set consisted of four weekly sessions.

In the first set, 10 panelists were selected from the staff, students, and technicians in the Department of Food Science. For each session, the judges were called into the test panel booths and were each given a scoring sheet (Figure 20). The instruction of the scoring method was explicitly given on the sheet. Each judge was then served with five coded samples in aluminium dishes arranged in random order. The coding of the samples was also randomized in every session, using different sets of numbers for each session.

The results from the first set of testing were then transformed into numbers of 1 to 5 designating 5 as the most desirable and 1 as the least desirable for every category of the characteristics including the overall ranking. The transformed results of the overall characteristic were then analysed for variances and variance ratios, both altogether and individually for each judge, with the aid of APL library programs on an IBM 360/67 computer.

From the results of the analysis, nine judges were picked out of ten, based on their "Day" variance ratios. High "Day" variance ratio means significant variation within a judge from one day to another in his judgment. The nine

judges, chosen from those with low "Day" variance ratios, were used in the second set of the test panel.

In the second set, a modified scoring sheet (Figure 21) was used so that the judges could score each characteristic directly in numbers ranging from 1 to 9, designating 9 as the most desirable and 1 the least desirable. Variances, variance ratios and other correlations were then computed for these scores.

A Duncan's New Multiple Range Test, as outlined by Duncan (1955), was also performed on the average scores of the overall characteristic of the samples.

TEXTURE PANEL OF MASHED POTATOES

DATE:_____
NAME:_____

Definitions:

Firmness: ease of teeth penetration into the sample and the breakdown of the sample on chewing thereafter.
Smoothness: mouthfeel on chewing.
Glueyness: elastic response on chewing and tendency of the sample to stick to teeth or gums.
Overall: overall textural characteristics of the sample.

Scoring Method: Check one (x) value of each characteristic for each sample. **Disregard flavor or color differences.**

Characteristic		Sample Number				
		1	2	3	4	5
Firmness:	very firm					
	firm					
	slightly firm					
	soft					
	very soft					
Smoothness:	very smooth					
	smooth					
	slightly coarse					
	coarse or grainy					
	lumpy					
Glueyness:	not gluey					
	slightly gluey					
	moderately gluey					
	gluey					
	very gluey					

Ranking Test: Disregard flavor or color differences, insert the number of the sample in an appropriate class with respect to their textural qualities. One or more sample can be in any one class but **none** can be in more than one class.

Excellent Very Good Good Pair Unsatisfactory

Comment: Please give your comment or suggestion on the testing method or on color, flavor, and texture of any sample in the space below:

Figure 20. Scoring sheet for the first set of texture panel evaluation.

TEXTURE PANEL OF MASHED POTATOES

DATE:_____
NAME:_____

Definitions:

Firmness: ease of teeth penetration into the sample and the breakdown of the sample on chewing thereafter.
Smoothness: mouthfeel on chewing.
Glueyness: elastic response on chewing and tendency of the sample to stick to teeth or gums.
Overall: overall textural characteristics of the sample.

	Parameter			
Range of score	Firmness	Smoothness	Glueyness	Overall
9	extremely firm	extremely smooth	not gluey	excellent
8				
7	moderately firm	moderately smooth	slightly gluey	very good
6				
5	not firm	not smooth	moderately gluey	acceptable
4				
3	moderately soft	moderately coarse	gluey	not acceptable
2				
1	extremely soft	extremely coarse	extremely gluey	awful

Scoring Method: Insert one figure corresponding to the considered score of each parameter as given above in an appropriate box for each sample and each parameter.

Parameter	Sample Number
Firmness	
Smoothness	
Glueyness	
Overall	

Comment:

Figure 21. Scoring sheet for the second set of texture panel evaluation.

VIII. OBJECTIVE MEASUREMENT OF TEXTURE

1. Materials:

i. The mashed potato samples were the same as those used for the sensory evaluation (SECTION B: VII.).

ii. A texturometer (SECTION B: II.) with a 2 in diameter flat-surface plunger.

iii. Daytronic Transducer Amplifier-Indicator Model 300D. Daytronic Corp., Dayton, Ohio.

iv. Moseley 135A X-Y Recorder with an output range of 0.5-50 mv/in Hewlett-Packard, Moseley Division, Calif.

v. A plastic vial of known internal volume (3 cm internal diameter, 4 cm internal height).

vi. Ott-Planimeter. Burrell Corp., Pittsburgh, Pa.

2. Methods:

a. Measurement of firmness and glueyness.

During the second set of texture panel testing, after each session, the same samples were used for the objective measurement. All measurements were done at room temperature.

For the texture measurement, a cylindrical sample of 0.75 in diameter and 0.75 in height was prepared using a

cork borer and a wire cheese cutter, by carefully packing the product into the cork borer so that no air was occluded in the sample. The uniformly packed sample was then cut at both ends with the wire cutter to the required size.

The sample was placed squarely in the center of the load cell platform. The plunger was driven downward at a constant speed of 5.7 in/min directly on to the sample until it was compressed to 1/6 of the original height. The plunger was then immediately reversed upward until it was pulled clear of the sample surface. Three replicates were measured for each sample.

The forces needed to compress the sample and to pull the plunger clear of the sample surface were recorded directly on the Moseley X-Y recorder with the pen moving at a uniform velocity in the X direction. A typical force-time curve is shown in Figure 22.

The areas A1 and A2 were then measured using the planimeter.

b. Determination of density.

The density at room temperature of the samples in the last three sessions of the second set of the texture panel testing was determined. This was done in duplicate by carefully packing the product into the plastic vial avoiding trapping air inside the sample. The vial was then weighed on an analytical balance. The weight of the

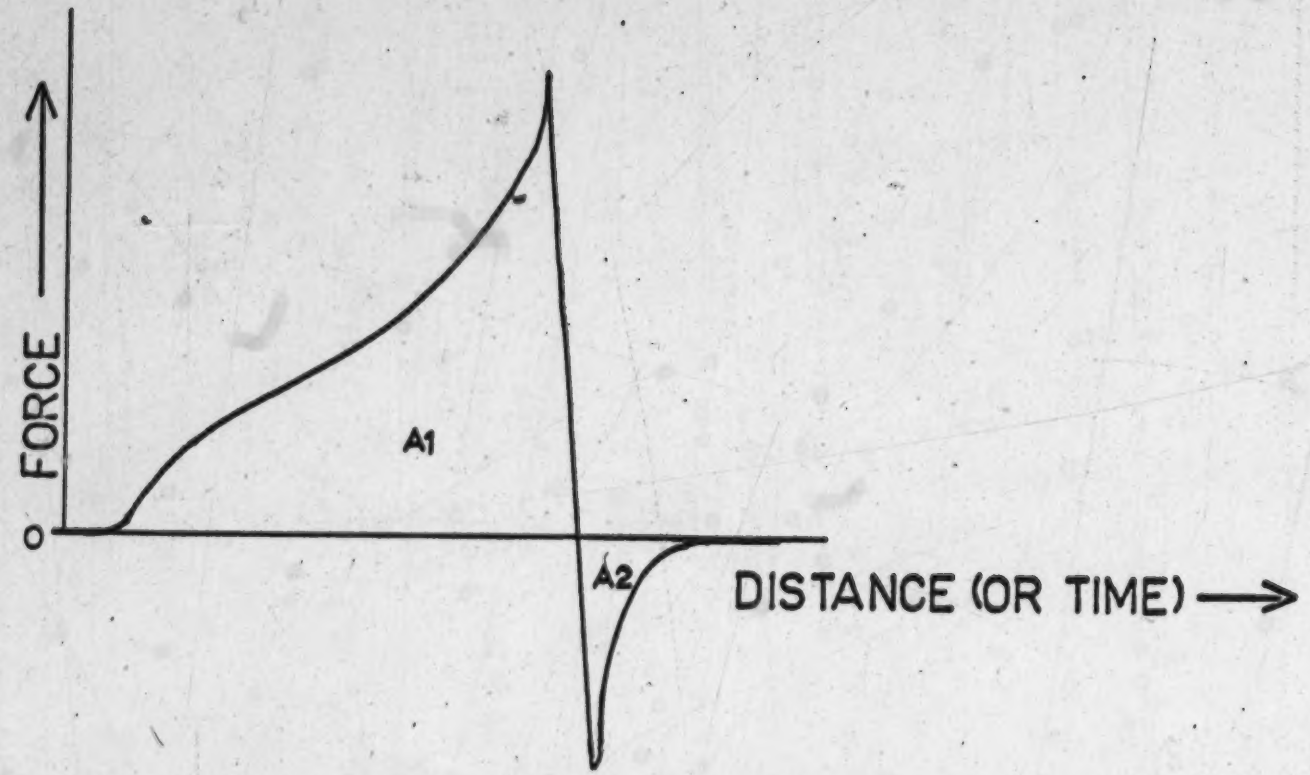


Figure 22. A typical force-distance (or time) curve from the texturometer.

sample divided by the internal volume of the vial represents the bulk density of the sample.

The results from both a. and b., together with those from the sensory evaluation in the preceding section were analysed for their variances, variance ratios, and correlation coefficients with the aid of the computer.

SECTION C. RESULTS AND DISCUSSION

I. EFFECTS OF COOKING ON PECTIC SUBSTANCES IN POTATOES

1. Starch interference in color development of D-galacturonic acid with carbazole reagent

At low concentrations of dissolved starch gel in the solution, as normally encountered in the pectic substances extracts from potatoes, the intensity of the color developed in the carbazcle reaction increases linearly with the increase in the concentration of the gel in the solution (Figure 4). The range of the potato starch gel concentrations, within which the linearity exists, is 0.0-0.036% (w/v).

The intensity of the color developed by D-galacturonic acid also increases linearly with the increase in its concentration (0.05% w/v) in the solution (Figure 4).

When starch gel and D-galacturonic acid solutions were combined in appropriate ratios so that neither starch gel nor D-galacturonic acid concentration in the mixture exceeds 0.036% and 0.05% respectively, the intensity of the color developed by the mixture in the carbazole reaction also increases linearly. The color intensity of the mixture in all cases is equivalent to the combination of the color developed by the pure starch gel at the concentration added and that by the pure D-galacturonic acid added. Thus it can be concluded that at low concentrations of starch in the

extract the effect of the starch in the color development reaction is additive.

At high starch concentrations (0.1% w/v), the intensity of the color developed by the starch departs from linearity while that by pure D-galacturonic acid remains linear (Figure 5). Though the color intensity of the mixture of the gel and the acid appears to be linear, the correction curve constructed for this region of starch concentrations (Region b, Figure 6), however, does not show linearity as in region a, hence its usefulness for the correction is doubtful. It is thus imperative that the starch concentration in the pectic substances extract, as measured in terms of its Blue Value Index, must be kept within the linear region of the correction curve. It was found that with the proposed extraction method, the starch concentrations in both water-soluble and Calgon-soluble fractions were within this desired range. It was not found possible to keep the starch concentration sufficiently low when the potato residue was extracted further with HCl solution as done by Bettelheim and Sterling (1955). This may be due to the fact that HCl readily hydrolyses potato cell wall, which normally keeps the gelled starch intact within its boundary, thus more of the starch is dissolved into the extract. In fact, on every occasion when attempts were made to investigate the HCl-soluble fraction, the extract had to be diluted several times before the intensity of the blue

color was sufficiently low for the colorimetric measurement. Furthermore, when this fraction was analysed without dilution for its carbazole value, the intensity of the color developed was too high to be measured with reasonable accuracy. This extreme intensity was thought to be due to the excessively high concentration of the starch rather than the pectic substances which may or may not, in fact, be present in the extract.

It is apparent from Tables 7 and 8 that without the correction for starch interference, the results of the uronide contents in the extracts would have been too high in most cases, and the reproducibility of the analyses would have been poor.

2. Pectic substances in raw potatoes

The pectic substances of raw potatoes are shown in Table 9 along with pectic substances for cooked, and for dried potatoes. The pectic substances of raw potatoes in both water-soluble and Calgon-soluble fractions are surprisingly low. This may suggest that pectic substances in Netted Gem potatoes used in this experiment are mainly in tightly bound forms. The water-soluble pectin appears to be higher than the Calgon-soluble pectin. This is contrary to those reported by Bettelheim and Sterling (1955) for the same variety of potatoes. The combined amounts of these fractions are, however, comparable. The fact that the quantity of pectic substances extracted by Calgon solution

Table 7. Water-soluble fraction of pectic substances in potatoes.

Sample		Sample wgt., gm	Volume extract, ml	Blue value	Correction value	Total carbazole value	Corrected carbazole value	Uronide content µg/2 ml extract	Uronide content mg/100 gm sample
Raw:	1	5	100	0.184	0.0030	0.017	0.0140	3.0	48.0
	2	5	100	0.388	0.0064	0.017	0.0106	2.2	35.2
	3	5	100	0.094	0.0018	0.019	0.0172	3.4	54.4
Cooked:	1	5	70	0.488	0.0078	0.125	0.1172	26.4	295.0
	2	5	100	0.715	0.0115	0.078	0.0665	15.1	242.0
	3	5	70	1.000	0.0160	0.131	0.1150	26.0	292.0
	4	5	70	0.800	0.0130	0.125	0.1120	25.5	285.6
Granules:	1	2	80	0.069	0.0013	0.160	0.1587	35.5	1136.0
	2	2	100	0.069	0.0013	0.126	0.1247	28.0	1120.0
	3	2	100	0.066	0.0013	0.127	0.1257	28.1	1124.0

Table 8. Calgon-soluble fraction of pectic substances in potatoes.

Sample		Sample wgt., gm	Volume extract, ml	Blue value	Correction value	Total carbazole value	Corrected carbazole value	Uronide content µg/2 ml extract	Uronide content mg/100 gm sample
Raw:	1	5	100	0.100	0.0019	trace	trace	trace	trace
	2	5	100	0.167	0.0028	0.011	0.0082	1.70	27.2
	3	5	100	0.100	0.0019	0.010	0.0081	1.70	27.2
Cooked:	1	5	70	0.288	0.0048	0.029	0.0242	5.20	58.2
	2	5	100	0.307	0.0050	0.018	0.0130	2.80	44.8
	3	5	60	0.480	0.0075	0.035	0.0275	6.20	59.5
	4	5	60	0.400	0.0065	0.029	0.0225	5.00	48.1
Granules:	1	2	70	0.144	0.0023	0.035	0.0327	7.20	202.0
	2	2	100	0.128	0.0021	0.018	0.0159	3.20	128.0
	3	2	100	0.220	0.0035	0.024	0.0205	5.00	200.0

Table 9. Quantities of pectic substances in raw and cooked potatoes, and in potato granules.

Sample		Water-soluble mg uronide/100 gm sample		Calgon-soluble mg uronide/100 gm sample		Apparent total mg uronide/100 gm sample	
		wet basis	dry basis	wet basis	dry basis	wet basis	dry basis
Raw:	1	48.0	212	trace	trace	48.0	212
	2	35.2	155	27.2	120	62.4	275
	3	54.4	240	27.2	120	81.6	360
Average		45.9	202.4	18.1	80.0	64.0	282.4
Cooked:	1	295	1296	58.2	256	353	1551
	2	242	1063	44.8	197	287	1260
	3	292	1282	59.5	261	351	1544
	4	286	1254	48.1	211	334	1465
Average		278.7	1223.8	52.6	231.2	331.3	1454.9
Granules:	1	1136	1190	202	211	1338	1402
	2	1120	1174	128	134	1248	1308
	3	1124	1178	200	210	1324	1388
Average		1126.7	1180.8	173.3	185.0	1303.3	1365.8

is low and the "apparent total" obtained from raw potatoes is much lower than that from cooked potatoes and the granules may suggest that most of the water-insoluble pectic substances in the Netted Gem potatoes are not bound together by metal ions such as Ca^{++}, but instead are bound by other stronger bonds as well as by physical enmeshing of the polymers in cellulosic fibers of cell walls. These bonds cannot be broken or weakened simply by the sequestering and hydrolysing actions of the acidified Calgon solution used in the extraction. Higher energy such as heat in cooking may have to be supplied to disrupt these bonds before the extraction with Calgon solution can be effective.

3. Pectic substances in cooked potatoes

Water-soluble pectic substances are increased six fold while the Calgon-soluble fraction is increased three fold by cooking. Cooking may thus be the most effective method to weaken or dissolve a major part of the cell wall binding materials in vegetables such as potatoes. Cell separation can be easily accomplished after cooking. Disruption of the cell wall during cell separation is avoided partly because part of the pectic substances not rendered water-soluble by cooking, i.e. the Calgon-soluble fraction still gives strength and flexibility to the cellulose fibres which form the main structure of the cell wall. The "apparent total" pectic substances obtained from the cooked Netted Gem potatoes is 1.45% dry basis as

compared with 0.7-1.5% dry basis reported by Potter and McComb (1957), and 2.4-3.9% dry basis reported by Hoff and Castro (1969). This suggests that Netted Gem potatoes grown in Southern Alberta contain average amounts of pectic substances, and that after cooking a major portion of them is rendered water-soluble, while most or all of the remaining pectic material is in Calgon-soluble form and is hence available to add strength to the cell wall.

It may be possible to vary the ratio between water-soluble and Calgon-soluble fractions in cooked potatoes by the cooking method used. In water-cooking, most of the water-soluble pectic substances may be lost in the cooking water. The temperature and length of time employed in cooking undoubtedly determine the extent to which the pectic substances change. It may thus be possible, as far as pectic substances are concerned, to find optimum cooking conditions whereby an optimum amount of pectic substances is rendered water-soluble, and yet sufficient water-insoluble portion is retained to maintain the maximum strength of the cooked cell wall to withstand subsequent mechanical forces in mashing and granulation steps of granule production. More work is needed, however, before such conditions can be determined.

4. Pectic substances in potato granules

As expected, there is little change during the

subsequent stages of processing in as far as apparent total pectic substances are concerned. This reflects the fact that the amounts of both water-soluble and Calgon-soluble pectic substances of potato granules remain almost the same as they were in the freshly cooked potatoes (Table 9). This is particularly true as steam-cooking is used, and no loss through "drips" or "expressed juice" occurs in the subsequent processing steps.

II. EFFECTS OF TEMPERATURE OF COOKED POTATOES ON THEIR FIRMNESS

1. Minimizing the variation within and between tubers

Results from trial runs for puncture and compression tests on cooked potatoes (Tables 10 and 11) are in agreement with those reported by Voisey et al. (1969) which showed that firmness of potatoes varies widely among different parts of a tuber. It appears, however, that careful selection of sample tubers for similar size and shape and the effects of cooking have reduced the variation of the firmness within tuber somewhat. For the compression test, samples taken around the middle part give results which are in reasonably close agreement. The two lowest values (Figure 12, positions 6 and 10) were rather closer to the edge of the tuber than the other samples. This may indicate that the compressive strength is lower near the

Table 10. Results of the trial compression tests.

Location	Force at breaking point, gm
1	769
2	725
3	730
4	823
5	748
6	559
7	799
8	846
9	853
10	645
Average	749.7

Table 11. Results of the trial puncture tests.

Location	Relative area under curve
1	73
2	51
3	62
4	60
5	44
6	58
7	76
8	66
9	70
10	56
11	72
12	43
13	71
14	75
15	40
Average	61.1

outside of the potatoes where the amount of cooking is greatest.

For puncture test, however, no definite pattern could be drawn. Thus, in the subsequent puncture tests, it was decided that the tests should be performed along or parallel to the longitudinal axis of the tuber.

Further attempts were made to reduce the variation between tubers. This was accomplished by the fact that, where possible, the same tuber was used for the measurements over the whole range of temperatures starting from highest to lowest. Hence, any variation in the results that is not due to the change in temperature will be due only to the variation within the tuber itself, which can be kept to a minimum if appropriate parts of the tuber are chosen for the tests.

2. Effects of temperature and freezing and thawing on firmness of cooked potatoes and on percentage of broken cells after mashing

The results of the puncture and compression tests at various temperatures of cooked potatoes are shown in Table 12. It is apparent that temperature has a profound effect on the strength of cooked potato tissue as measured by both tests. Figures 23 and 24, in which compressive force (log) and relative area (log) for puncture test, respectively, are plotted against temperature of the cooked

Table 12. Firmness of intact cooked potato tissue by puncture and compression tests at various temperatures.

Sample No.	Puncture test, relative area under curve							Compression test, force at breaking point, gm						
	Sample temp. after cooking, °C				After freeze-thaw			Sample temp. after cooking, °C				After freeze-thaw		
					Reheat		Recool					Reheat		Recool
	80°	40°	25°	10°	5°	75°	25°	80°	40°	25°	10°	5°	75°	25°
1	66	81	88	118	52	43	45	694.9	1389.7	1583.1	2175.2	755.3	302.1	604.2
2	66	79	83	104	64	33	60	713.0	1223.6	1661.6	2072.5	755.3	332.3	716.0
3	67	70	106	140	61	47	56	619.3	1492.5	1848.9	2135.9	755.3	356.5	604.2
4	68	86	92	112	55	38	45	728.1	1462.2	1752.3	2217.5	758.5	416.9	589.2
Average	66.8	79	92.3	118.5	58.3	40.3	51.5	688.8	1392.0	1711.5	2150.3	762.8	352.0	628.4

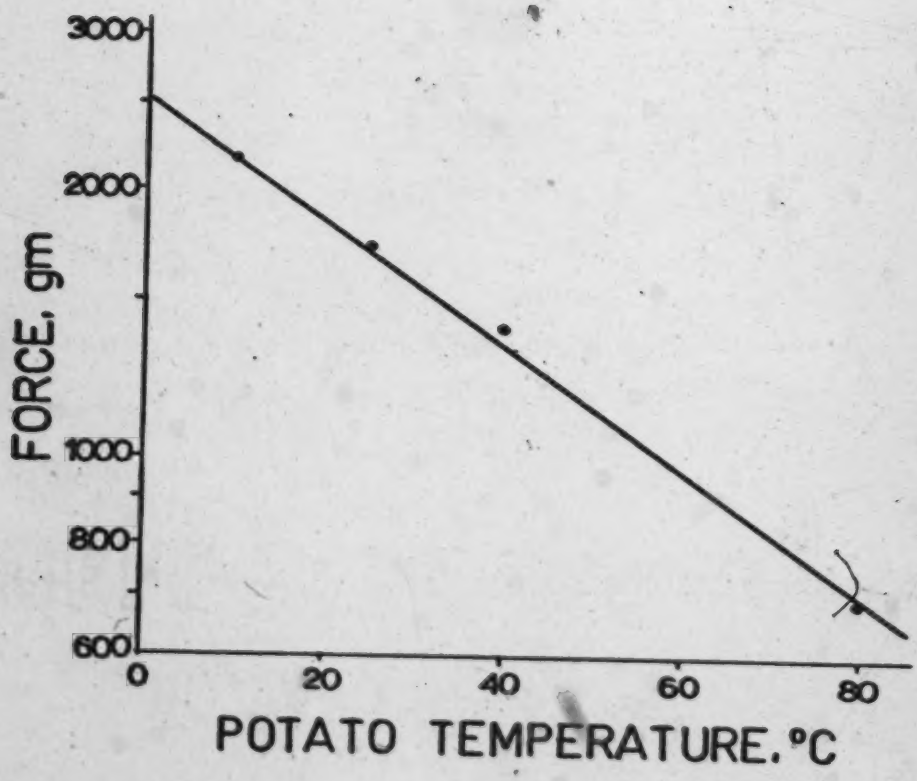


Figure 23. Effect of temperature on firmness of cooked potatoes as measured by compression test using a texturometer with a flat-surface plunger compressing a cylindrical sample on a load cell.

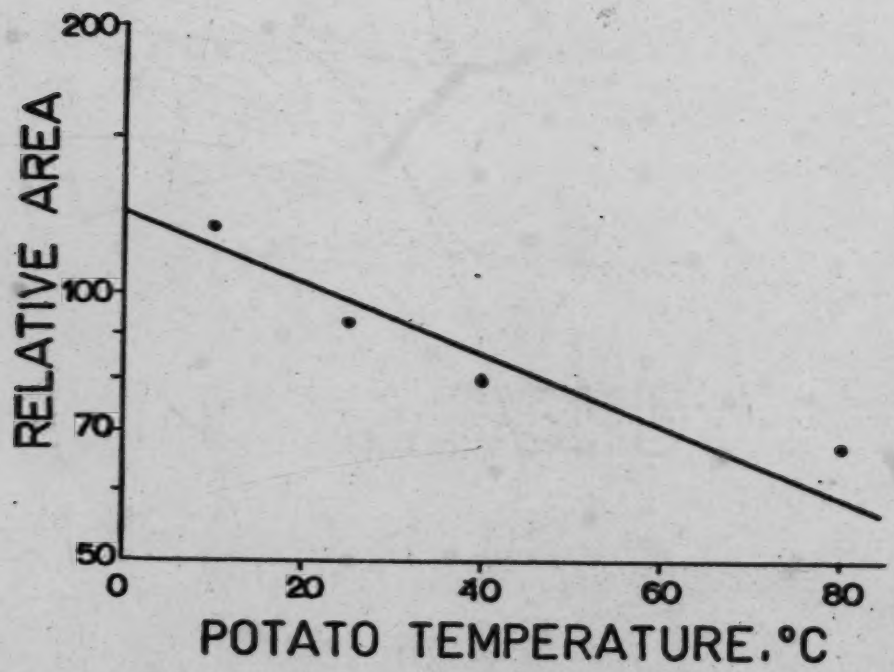


Figure 24. Effect of temperature on firmness of cooked potatoes as measured by puncture test using a texturometer with a cylindrical probe pushing into a sample on a load cell.

potatoes being measured, show that firmness of the intact tissue increases logarithmically with the decreasing temperature. This means that strength of the tissue decreases with increase in temperature. This, in turn, means that at higher temperatures, less force is needed to mash the potatoes. This may be due to the fact that at high temperature the chemical bonds in the gel network both inside and outside the cells are weakened by the heat energy. As the temperature of the cooked potatoes drops the resistance to cell separation increases as the gel starts to set and hence the binding forces between cell walls become stronger. This is expected to result in tearing or rupturing of the cell walls in many cases permitting the cell contents, which are essentially gelatinized starch, to escape. To confirm this, determinations were made of percentage of cells broken at various mashing temperatures, and the results are shown in Table 13. The percentage of broken cells increases very rapidly as the mashing temperature is reduced.

When the cooked potatoes were frozen and thawed, the force needed to puncture or compress the tissue was again reduced. At 5°C where the frozen potatoes were completely thawed, the force needed was similar to that with a temperature of 80°C. This may be due to the fact that while the amounts of the cell binding material, which consists essentially of pectic substances and extracellular

Table 13. Percentage broken cells in cooked potatoes mashed at various temperatures.

Temperature at mashing, °C		% Broken cells
After cooking:	80°	2.62
	40°	12.45
	25°	31.89
	10°	45.83
After freezing:	0° (partially thawed)	5.00
	10° (completely thawed)	2.20
	* 80° (reheated)	2.50
	* 25° (recooled)	18.50

* The samples were slightly darkened after reheating.

starch gel, were similar in both instances, at 80°C the formation of strong bonds in the gel network was prevented by high heat energy. Whereas, after freezing and thawing the major proportion of the starch gel was forced to retrograde (French, 1950) and most other bonds in the gel network were destroyed by ice crystals. When the thawed potatoes were reheated to 75°C the force required was decreased even further to lower than either that at 80°C or that at 5°C. This may be because the bonds in the network of the cell binding material broken during the freeze-thaw treatment were unable to reform, while the unbroken ones were weakened further by the increased heat energy. Reheating of the potatoes, however, was accompanied by the after-cooking darkening which is the result of the chemical reaction between metallic ions, particularly Fe, with phenolic compounds such as chlorogenic acid (Hawkins et al., 1959; Smith, 1958; Hughes et al., 1962; Hughes and Swain, 1962; Hughes and Evans, 1967, 1969). When the reheated potatoes were again cooled to 25°C the firmness again increased, but not to the same levels as observed with the samples without freezing and thawing.

This phenomenon has a direct bearing on the success of the process at the granulation step. During pre-drying, prior to granulation, the frozen and thawed mashed potatoes are reheated. The temperature of the potatoes during granulation was usually slightly lower than room temperature (about 25°C). It was found that if the potatoes

were not frozen and thawed prior to these steps, it was very difficult to keep the potatc tissue stirred during the pre-drying, and to separate the cells during the granulation, with the result that excessive damage to the potato cells occurred. Broken cell counts are not reported as the number of cells broken was so great as to make a cell count meaningless. With the intrcduction of the freezing and thawing step, however, this difficulty is overcome. Furthermore, the temperature of the potatoes during pre-drying and granulation steps does not usually rise much higher than rocm temperature, and is not sufficient to cause after-cooking darkening.

It should be noted, however, that if the frozen potatoes were not completely thawed before mashing, the potatoes sustained significant damage from the mechanical forces resulting in a higher percentage of broken cells than if they had been completely thawed (Table 13). This is conceivably due to the fact that the potato cells are bound together with ice which, on mashing, the rigid cells may be broken rather than separated as in the case of completely thawed potatoes. Also, the rigid ice crystals may damage the cells on impact during mashing. This observation is in contrast with the processing method patented by Rivoche (1951a, 1951b) in which the frozen potatoes were first reduced to a snow mist in a hammer mill prior to spray drying. The high proportion of damaged cells in the granules

produced with that method may attribute to the fact that the technique has never been used commercially.

When correlation coefficients were calculated directly from the values obtained from the experiment, that of the compression test vs temperature is significant at 1% level. The correlation coefficients of the puncture test vs compression test, % broken cell vs puncture test, and % broken cell vs compression test are significant at the 5% level, while those of the puncture test vs temperature, and % broken cell vs temperature are not significant (Table 14). However, when logarithmic values of the compression and puncture tests and of the % broken cell were calculated (Table 15) and plotted against temperature (Figures 23, 24, and 25) better correlations were obtained. The correlation coefficient of % broken cell vs temperature also becomes significant at 1% level. This suggests, as previously mentioned, that both firmness and % broken cell increase in logarithmic fashion with the decrease in temperature. The results also confirm the report of Voisey and coworkers (1969) that either simple puncture test or compression test can be used to measure the firmness of potato tissue. The results from the present experiment seem to suggest, however, that compression test is somewhat more suitable for evaluating the strength of the cooked potatoes. This is due to its somewhat better reproducibility, and higher correlations it gives with potato temperature and percentage broken cells.

Table 14. Correlation coefficients of relationships between measures of firmness, percentage of cells broken and temperature of unfrozen cooked potatoes.

Cofactors	r value	* Probability Level
Puncture test vs temperature	-0.9102	not significant
Compression test vs temperature	-0.9931	<0.01
% Broken cells vs temperature	-0.9327	not significant
Puncture test vs compression test	0.9525	<0.05
% Broken cells vs puncture test	0.9781	<0.05
% Broken cells vs compression test	0.9616	<0.05

*From Snedecor (1946).

Table 15. Correlation coefficients of relationships between measures of log values of firmness, percentage of cells broken and temperature of unfrozen cooked potatoes.

Cofactors	r Value	Probability Level
Log puncture test vs temperature	-0.9525	<0.05
Log compression test vs temperature	-0.9986	<0.01
Log % broken cells vs temperature	-0.9908	0.01
Log puncture test vs log compression test	0.9359	not significant
Log % broken cells vs log puncture test	0.9446	not significant
Log % broken cells vs log compression test	0.9875	<0.05

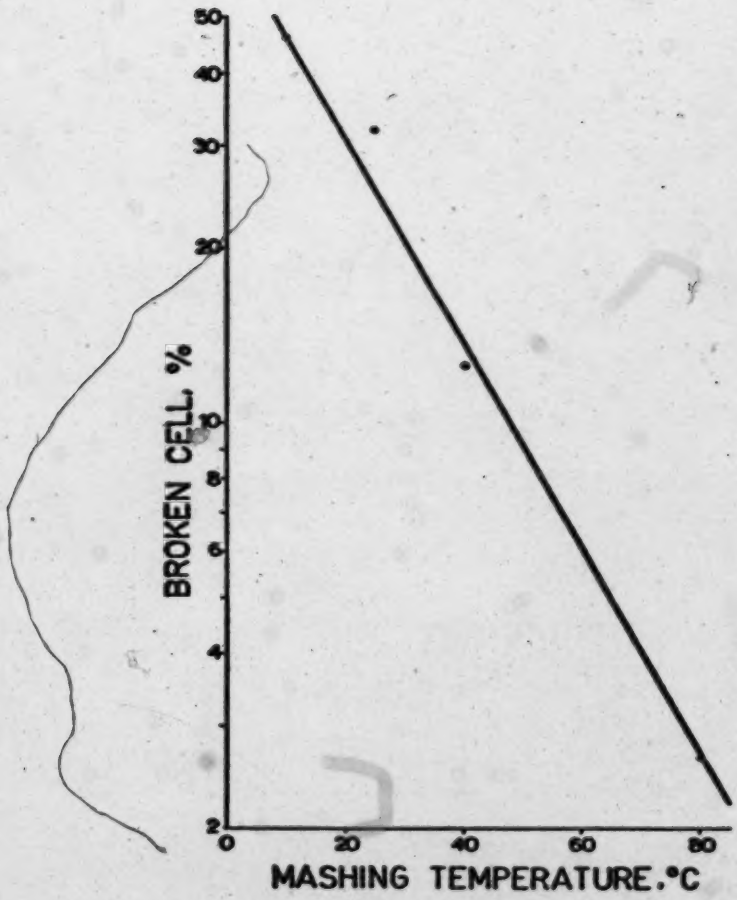


Figure 25. Effect of mashing temperature on percentage of broken cells. The cooked potatoes were mashed for 45 seconds at top speed in KitchenAid mixer. Broken cells were counted under microscope at 100x.

It would therefore appear that for successful mashing, the cooked potatoes must be mashed at high temperatures, preferably not lower than 70°C, using a relatively high speed mixer for an appropriate length of time so that the potato cells are completely separated into small units of single cell or aggregates of a few cells. Mashing should not be unnecessarily prolonged as this will also damage the cells as they are subjected to repeated compressive and shearing stresses while their temperature is gradually decreasing. Heat loss through evaporation should be reduced as much as possible by mashing in an enclosed space.

It would also appear that freezing and thawing is a necessary step in the proposed processing technique, as it further reduces the force necessary for the separation of the cells to a value lower than any other method. It makes possible pre-drying of the mash at an elevated temperature in a stirred-bed dryer, and granulation at room temperature or lower with little damage to the potato cells.

III. EFFECTS OF SURFACTANTS ON POTATO STARCH GEL

1. Effects of surfactants on pure amylose

Results in Table 16 and Figure 26 are in agreement with Osman *et al.* (1961) who showed that a surfactant reduces iodine affinity of amylose to a minimum value beyond

Table 16. Reduction of Blue Value Index (BVI)* of free amylose by Myvatex.

% Myvatex in 0.01 % amylose soln.	Absorbance, 640 nm
0.000	0.2820
0.001	0.2740
0.002	0.2665
0.003	0.2590
0.005	0.2390
0.007	0.2260
0.010	0.2175
0.020	0.1705
0.030	0.1770
0.050	0.1510

* Blue Value Index is the absorbance reading of starch-iodine complex at 640 nm.

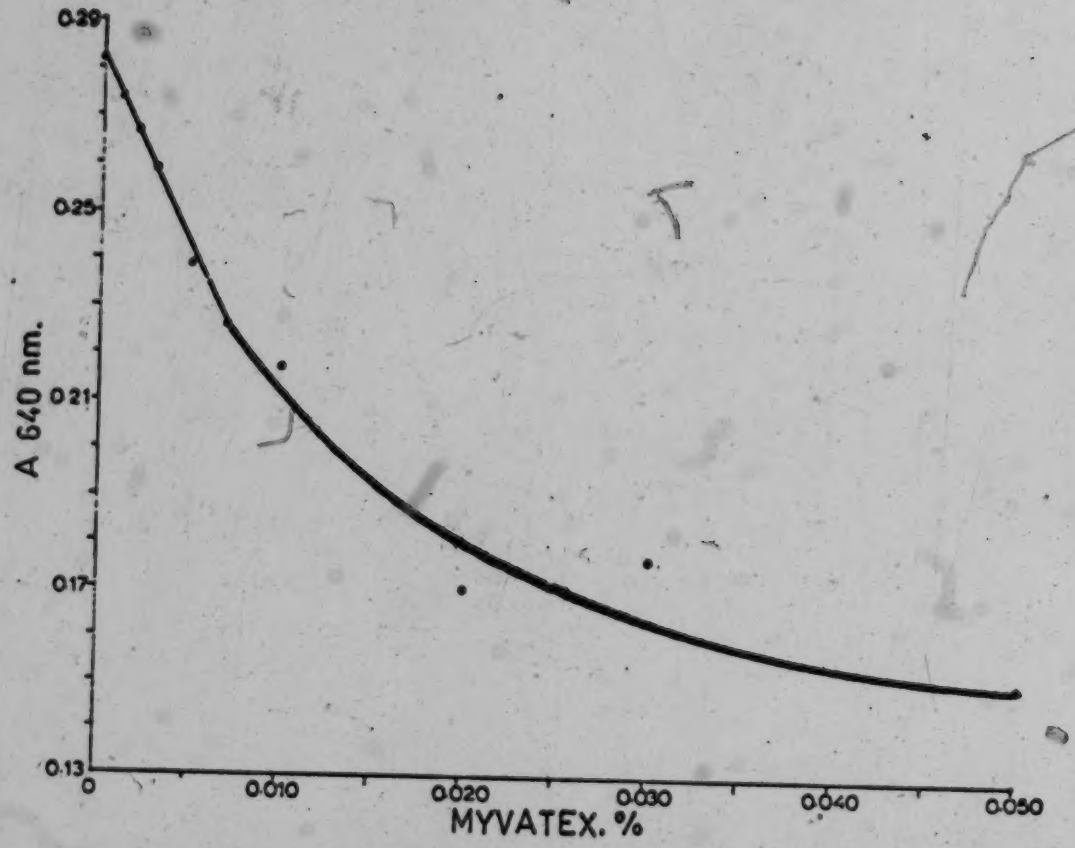


Figure 26. Reduction of Blue Value Index (BVI) of 0.01% amylose solution due to clathrate formation with Myvatex. BVI is the absorbance reading at 640 nm of the starch-iodine complex.

which it could be reduced no further by addition of more surfactant. Figure 26 shows that Myvatex can reduce the iodine affinity of amylose in direct proportion to its concentration in the solution, until the concentration increases to about 0.0075% when the effect starts to level off. The absorbance of the color complex appears to reach its minimum at about 0.05% Myvatex. At these relatively high concentrations of Myvatex the measurement of the absorbance becomes difficult due to the increasing opacity of the solution as a result of micelle formation by the surfactant.

2. Effects of surfactants on starch gel in cooked, mashed potatoes

Tables 17 and 18, and Figures 27 and 28 show the effects of Myvatex (a blend of glycerol monostearate (GMS) and propylene glycol monostearate (PGMS) with approximately 20% by weight of hydrogenated vegetable oil) and Myverol (distilled monoglycerides (essentially GMS) made from lard) as starch complexers in mashed potatoes. The reduction of the absorbance is almost linearly proportional to the increase of surfactant concentrations up to a certain level, after which no further reduction is apparent. In the case of Myverol, however, there is a curious and as yet unexplained situation whereby at the low concentrations of 0.05% for the samples analysed immediately after mashing and after chilling to 42°F, and of 0.05% and 0.1% for the samples analysed after freezing and thawing, their absorbance

Table 17. Effects of Myvatex on the amount of free starch in cooked, mashed potatoes as revealed by Blue Value Index.

% Myvatex	Absorbance, 640 nm					
	After Mashing		At 42°F		After Freeze-Thaw	
	Wet Basis	Dry Basis*	Wet Basis	Dry Basis*	Wet Basis	Dry Basis*
0	0.1265	0.5556	0.0878	0.3856	0.0407	0.1790
0.05	0.0980	0.4304	-	-	-	-
0.10	0.0797	0.3500	0.0668	0.2934	0.0260	0.1142
0.20	0.0577	0.2534	0.0642	0.2819	0.0199	0.0876
0.30	0.0700	0.3074	0.0685	0.3008	0.0204	0.0896
0.40	0.0600	0.2635	0.0662	0.2907	0.0233	0.1021
0.50	0.0605	0.1657	-	-	-	-
1.00	0.0830	0.3645	-	-	-	-

* Absorbance on dry basis is computed to enable direct comparisons to be made. The equation is:

$$A(dry) = 100\ A(wet)/(\%solids\ in\ sample)$$

Table 18. Effects of Myverol on the amount of free starch in cooked, mashed potatoes as revealed by Blue Value Index.

% Myverol	Absorbance, 640 nm					
	After Mashing		At 42°F		After Freeze-Thaw	
	Wet Basis	Dry Basis	Wet Basis	Dry Basis	Wet Basis	Dry Basis
0	0.1326	0.5823	0.0945	0.4150	0.0915	0.4018
0.05	0.1808	0.7938	0.1678	0.7367	0.1015	0.4458
0.10	0.1081	0.4747	0.1240	0.5446	0.1123	0.4930
0.20	0.0824	0.3619	0.0775	0.3404	0.0685	0.3008
0.30	0.0639	0.2809	0.0630	0.2767	0.0320	0.1405
0.50	0.0659	0.2894	0.0583	0.2558	0.0393	0.1724
0.70	0.0620	0.2723	0.0635	0.2789	0.0348	0.1526
1.00	0.0605	0.2657	-	-	-	-

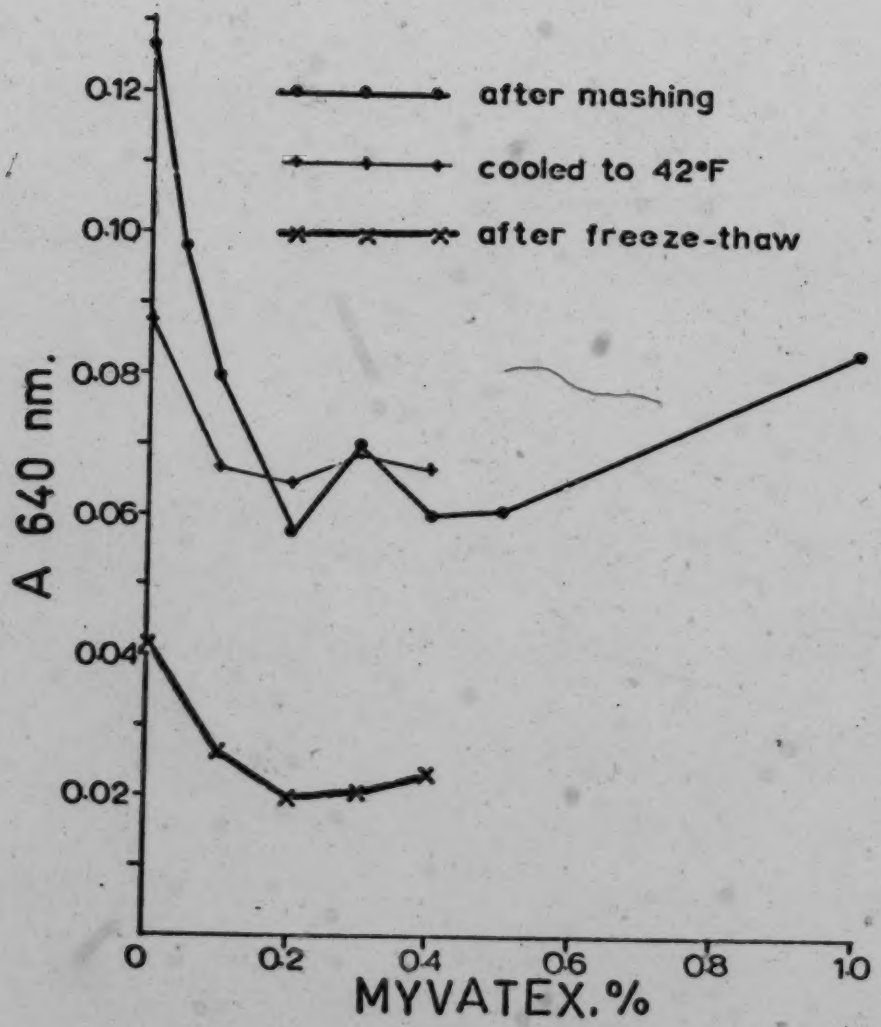


Figure 27. Effects of Myvatex on Blue Value Index (BVI) of starch in cooked mashed potatoes. The BVI is the absorbance reading at 640 nm of the starch-iodine complex.

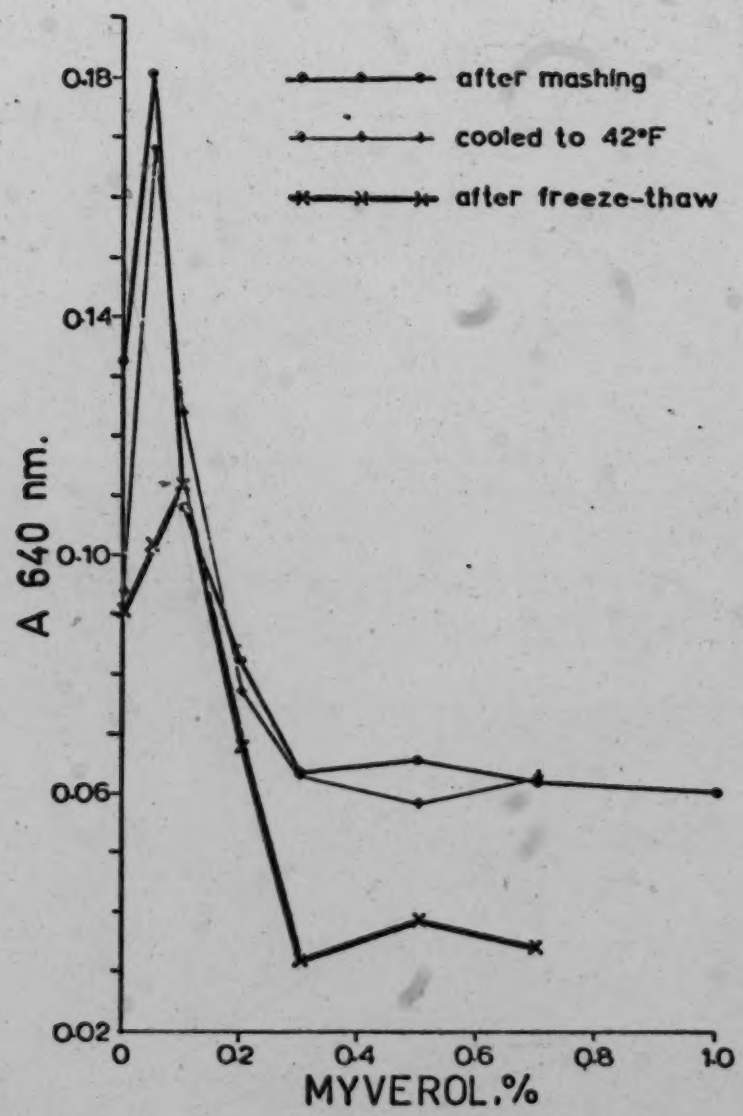


Figure 28. Effects of Myverol on Blue Value Index (BVI) of starch in cooked mashed potatoes. The BVI is the absorbance reading at 640 nm of the starch-iodine complex.

exceeds that of the sample to which no Myverol was added (Figure 28). Its behavior at higher concentrations, nevertheless, is essentially the same as that of Myvatex.

It is interesting to note that Myvatex which is a blend of glycerol monostearate (GMS), propylene glycol monostearate (PGMS) and hydrogenated vegetable oil appears to be more effective as a starch complexer in mashed potatoes than Myverol which consists essentially of GMS. Figures 27 and 28 show that the optimum concentration of Myvatex to produce minimum absorbance is 0.2% where as that of Myverol is about 0.3%. Furthermore, the minimum absorbance induced by Myvatex appears to be somewhat lower than that by Myverol, which may suggest that Myvatex can complex starch in mashed potatoes more completely. This may be due to the combined effects of GMS and PGMS in Myvatex. It has been shown (Birnbaum, 1955, 1971; MacDonald, 1968) that a multi-component emulsifier system performs better than any of its individual components even though the hydrophilic-lypophylic balance (HLB) value is the same for each system. This may be due to the formation of stronger surface films since several surfactants may fit together more intimately because of their structural configurations and form a more closely packed protective layer on the surfaces, with fewer interstitial voids than single component systems. Birnbaum (1971) stated further that combined surfactants also lower the concentration required

to achieve critical micelle concentration (CMC) as compared to a single surfactant species. This may account for the fact that less Hyvatex is needed to achieve the minimum absorbance than Hyverol.

When the mashed potatoes were cooled to below room temperature, e.g. 42°F, the absorbance of the control was considerably reduced. This is equivalent to the conditioning or tempering effect in the add-back process as reported by Olson and Harrington (1955), in which the starch gel which has not been complexed by surfactants undergoes retrogradation. The samples with surfactants added, however, show no appreciable difference in their absorbance at this temperature from that at higher temperatures. This is almost certainly because the major portion of the released starch gel which should have been available for retrogradation process at 42°F was complexed by the surfactants leaving very little or none to retrograde, at that particular temperature, to further reduce the absorbance.

When the mashed potatoes were frozen and thawed, however, the relatively stable starch gel which has not been complexed nor retrograded was forced to retrograde by the freezing process. This is in accord with the observation made by French (1950). Figures 27 and 28 show that even though the absorbance is reduced considerably by freezing and thawing alone, as in the case of the control, the effect is even greater with the addition of surfactants. It would

therefore appear that the use of surfactants is necessary in the freeze-thaw process to reduce the amount of free starch to a minimum value, and so make it possible to produce high quality potato granules using a direct process. With the freeze-thaw process the required levels of surfactants are well below the flavor threshold.

The above phenomenon is supported further by the data of Table 19 which shows that granules processed without surfactants added exhibit much higher blue value index (BVI) than those with surfactants added. It was found in the course of these studies that no acceptable granules could be produced, with the proposed direct process, without the aid of freezing and thawing even when surfactants were added. The mashed potatoes without freezing and thawing could not be pre-dried without causing extensive cell damage after which it was almost impossible to granulate them to fine powder. Some fine powder was produced without freezing and thawing, but on reconstitution the product was so gluey as to be entirely unacceptable as a mashed potato product.

As can be seen from the results in Table 19, the BVI of the granules processed with surfactants is slightly lower than that of the commercial flakes. The BVI of the commercial granules is much lower than that of other products. This is presumably due to the fact that apart from containing high amounts of surfactants and several other food additives such as vegetable fat, artificial flavors, and pepper, the particular commercial granules also contain

Table 19. Blue Value Index (BVI) of potato granules and flakes.

Sample	Absorbance, 640 nm	
	Wet Basis	Dry Basis
Granules processed without surfactants	0.1180	0.1232
Granules processed with surfactants	0.0440	0.0460
Commercial granules	0.0150	0.0160
Commercial flakes	0.0460	0.0497

considerable amounts of powdered skim milk, the combined amounts of which reduce the proportion of potato granules in the product appreciably.

The surfactants also have a significant effect on the texture of the reconstituted product. The texture panel, the details of which are discussed in Section C. VII. 1., rated the overall characteristics after reconstitution of the granules processed with surfactants, using the proposed technique, comparable or slightly better than those of the commercial granules and flakes used in the tests.

It would appear from these experiments that the use of surfactants significantly improves the quality of the product, and it is therefore recommended that they be used in any process using the freeze-thaw technique. Myvatex seems to be superior to Myverol for this purpose and is easier to handle as it is in granular rather than a pasty form. It can be added to the potatoes while being mashed as the heat from the cooked potatoes is sufficient to melt it down so that it can be thoroughly mixed with the potatoes. The level of Myvatex used should be at least 0.2% based on cooked potato weight. Excessive amounts of the surfactant, however, are not useful, and in fact, can lead to an undesirable "soapy" flavor in the product.

IV. EFFECTS OF SURFACTANTS ON PECTIC SUBSTANCES

When surfactants were added to a clear pectin solution it becomes opaque. The opacity increases with the increasing concentration of the surfactants. This cloudiness may be attributed to the precipitation of pectin by the surfactants at low concentrations in similar manner to precipitation of amylose by surfactants. At higher surfactant concentrations, the opacity may be attributed to both the precipitation of pectin molecules as well as the formation of micelles by the surfactant molecules themselves. Birnbaum (1971) reported that there is a critical micelle concentration (CMC) for a surfactant in an aqueous solution at which micelles start to form. He was of opinion that at very low concentrations the surfactants are present in the aqueous phase as single molecules. As the concentration is increased the surfactants molecules can withdraw their lipophilic groups from aqueous environment by adsorption as an oriented monolayer, or by forming micelles. At still higher concentrations, the surfactants form liquid-crystalline mesophases or dispersions. When the concentrations are high enough as in the cases of 0.5% Hyvatex and higher (Table 20), and 0.05% Hyverol and higher (Table 21) the micelles coalesce and form large globules most of which float to the top of the solution.

The viscosity of pectin solution decreases with the increase in surfactant concentration until a minimum is reached after which further addition of the surfactants has no effect or, in most cases, increases the viscosity

Table 20. Effects of Hyvatex on viscosity of pectin solution.

% Hyvatex in 1% pectin gel													
0.000		0.030		0.050		0.075		0.100		0.200		0.500**	
Temp. °C	Visc. cp*	Temp. °C	Visc. cp*	Temp. °C	Visc. cp*	Temp. °C	Visc. cp*	Temp. °C	Visc. cp*	Temp. °C	Visc. cp*	Temp. °C	Visc. cp*
73.8	1.745	73.5	1.770	83.8	1.695	85.0	1.515	81.0	1.545	65.5	1.920	76.0	1.895
68.9	1.795	68.9	1.830	75.0	1.730	79.7	1.630	76.2	1.580	63.5	1.960	71.0	1.940
63.9	1.880	64.2	1.890	68.5	1.830	70.5	1.760	70.9	1.670	60.0	1.985	69.0	1.945
57.2	2.030	61.5	1.980	63.9	1.920	63.9	1.820	60.0	1.845	57.4	2.040	64.0	2.040
52.9	2.145	45.5	2.450	57.8	2.035	55.3	2.060	54.2	1.955	54.8	2.045	55.8	2.250
50.2	2.250	44.5	2.500	53.8	2.175	51.9	2.210	49.8	2.020	52.8	2.140	51.5	2.285
46.9	2.325	44.3	2.480	49.5	2.310	48.7	2.280	46.9	2.148	51.3	2.180	47.8	2.410
43.9	2.445	30.0	3.140	46.1	2.415	45.5	2.375	43.7	2.240	50.2	2.180	46.0	2.480
40.5	2.550	29.8	3.180	43.7	2.500	43.8	2.440	38.7	2.370	49.0	2.210	43.2	2.600
38.5	2.590			41.8	2.545	41.8	2.500	35.0	2.510	40.0	2.500	41.0	2.670
37.0	2.640			31.0	3.050	38.5	2.645	28.8	2.775	38.9	2.550	38.0	3.020
				23.8	3.485	37.8	2.670	22.9	3.040	38.2	2.570	28.9	3.310
						28.9	3.080			37.5	2.580		
						25.9	3.250			37.0	2.585		
										33.0	2.730		
										27.5	3.060		

* cp = centipoise

** Quantities of the surfactant formed large globules and floated to the surface of the solution when cooled.

Table 21. Effects of Myverol on viscosity of pectin solution.

% Myverol in 1% pectin gel											
0.000		0.020		0.030		0.050*		0.100*		0.200*	
Temp. °C	Visc. cp	Temp. °C	Visc. cp	Temp. °C	Visc. cp	Temp. °C	Visc. cp	Temp. °C	Visc. cp	Temp. °C	Visc. cp
74.2	1.580	75.0	1.510	75.0	1.530	80.6	1.390	79.6	1.545	86.0	1.440
69.0	1.635	70.0	1.575	70.0	1.610	74.3	1.480	75.2	1.570	82.5	1.480
66.5	1.680	65.0	1.650	65.0	1.685	68.0	1.505	63.5	1.740	79.9	1.520
63.9	1.745	60.0	1.730	60.0	1.775	65.0	1.580	55.8	1.885	72.7	1.610
60.7	1.805	55.0	1.830	55.0	1.875	59.6	1.655	51.3	1.998	67.9	1.680
58.0	1.855	50.0	1.935	50.0	1.975	56.8	1.670	47.5	2.080	59.2	1.820
53.3	1.974	45.0	2.050	45.0	2.095	55.5	1.690	43.5	2.178	53.4	1.960
48.8	2.085	40.0	2.210	40.0	2.245	52.9	1.750	39.9	2.270	49.2	2.024
48.3	2.125	35.0	2.380	35.0	2.430	46.5	1.884	39.6	2.285	32.7	2.515
46.1	2.125	30.0	2.565	30.0	2.615	44.5	1.920	25.9	2.805	31.5	2.555
45.7	2.150	25.0	2.820	25.0	2.880	40.2	1.960	25.8	2.800	30.3	2.605
26.9	2.875					37.8	2.077			29.8	2.635
						36.3	2.090				
						35.2	2.140				
						34.0	2.170				
						25.3	2.498				

* Quantities of Myverol in the solution coalesced and floated to the top of the solution when cooled. The amount of coalesced Myverol increased with increasing % Myverol in the solution.

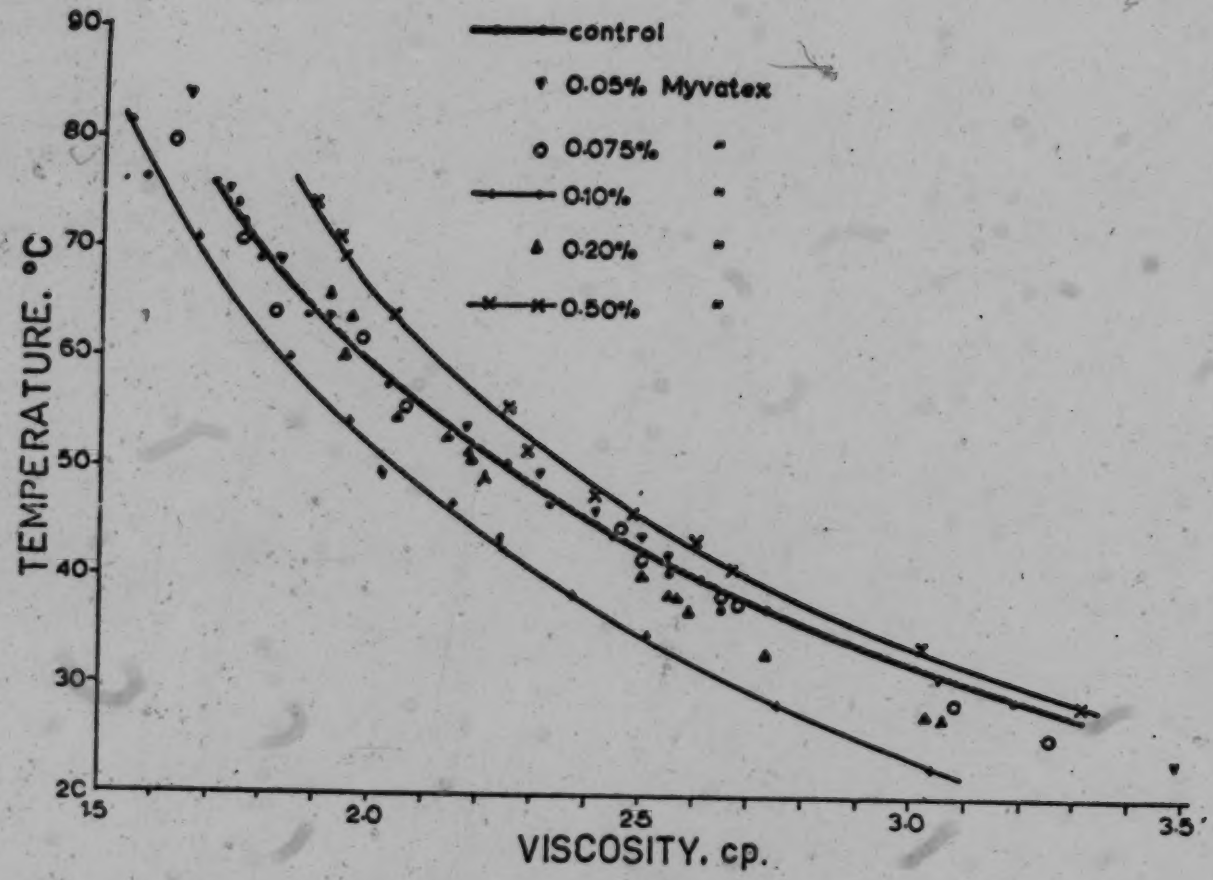


Figure 29. Effects of Myvatex on viscosity of pectin solution. The viscosity was measured using Brookfield Synchro-Lectric Viscometer Model RVT with the spindle No. 1 and the speed of 100 rpm.

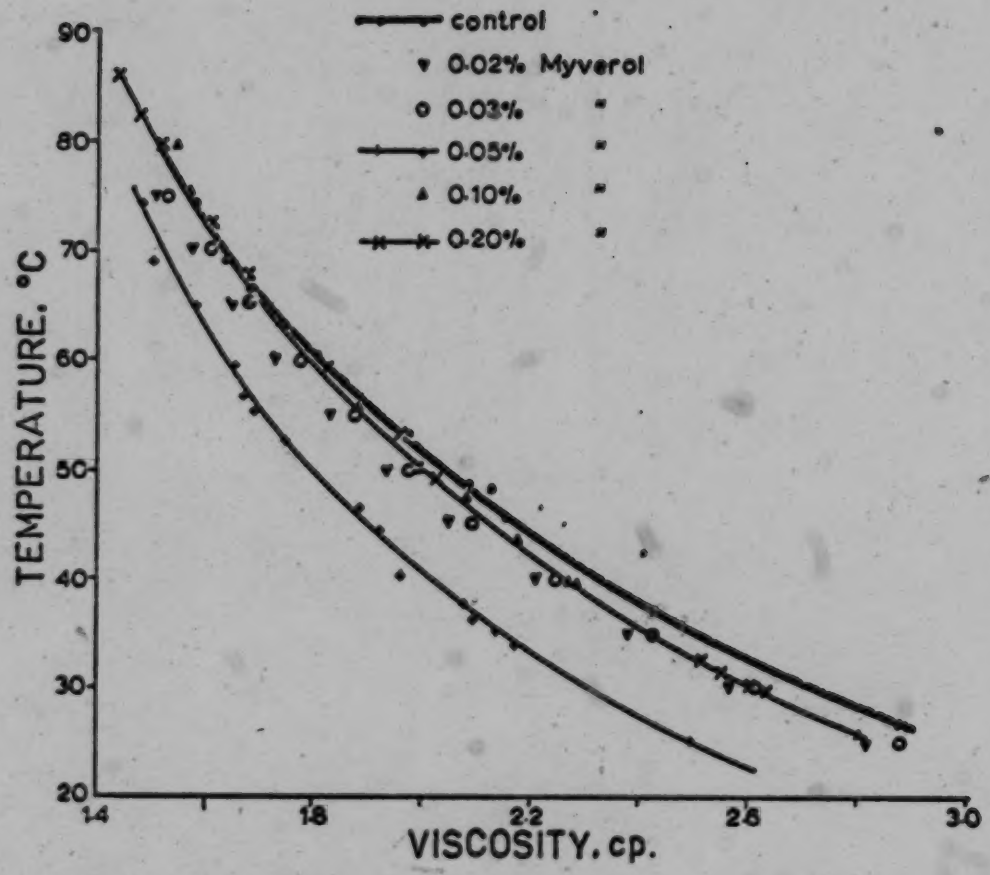


Figure 30. Effects of Myverol on viscosity of pectin solution. The viscosity was measured using Brookfield Synchro-Lectric Viscometer Model RVT with the spindle No. 1 and the speed of 100 rpm.

(Figures 29, 30, 33, and 34). The decrease of the solution viscosity at low surfactant concentrations may be explained that since the pectin molecule is a linear chain of galacturonic acids linked together by α-1,4 linkages, as in amylose chains where glucose units are similarly linked, it is possible that the pectin chain with certain amounts of methylation can form complexes with monoglycerides. This may be accomplished by the linear chain rearranging itself into a helical configuration enveloping the monoglyceride molecules, such as the clathrates formed between amylose chain and surfactants. The formation of the complex, however, may be far from complete due to strong polarity exerted by the carboxyl groups in the pectin chain which tend to repulse each other. Hence, degree of methylation of the carboxyl groups may be very important in such a case. The higher the degree of methylation the more intimate the neighboring galacturonide moieties can come together to form a helical structure. The ionic nature of the surfactants may also play an important role in the complex formation.

If such complexes are formed, the pectin chains would be at least partially withdrawn from the gel network resulting in the decrease in the solution viscosity. The amounts of the complexes would increase with the increasing concentration of the surfactants until the saturation point is reached, after which the viscosity of the mixture would again increase due to the formation of the micelles and

globules by the extra amounts of the surfactants. The hypothesis that the increased solution viscosity is contributed by the excessive amounts of the surfactants is further supported by the evidence obtained from measuring the viscosity of the surfactants dispersed in distilled water. The data presented in Tables 22 and 23, and Figures 31 and 32 show that both Myvatex and Myverol cause the viscosities of the dispersions to be greater than that of distilled water, particularly at high concentrations.

Further work, possibly using experimental techniques such as X-ray diffraction is necessary to ascertain whether or not pectins do form complexes with surfactants. Pectins of varying degree of methylation should be used to determine whether the number and spacing of unprotected carboxyl groups are, in fact, the factors limiting the extent of the complex formation.

For practical purposes in production of potato granules, it should be noted then that the surfactants not only reduce the stickiness exerted by the starch fraction, but they also reduce the strength of the pectin gel in the mashed potato matrix which is formed after cooking and mashing. Thus, the separation of the cooked potato cells during pre-drying and granulation can be accomplished even more easily because of this extra function of the surfactants.

It is interesting to note also that, contrary to

Table 22. Viscosity of Myvatex dispersed in water.

% Myvatex							
0.000		0.05		0.10		0.20	
Temp. °C	Visc. cp	Temp. °C	Visc. cp	Temp. °C	Visc. cp	Temp. °C	Visc. cp
78.5	0.820	82.0	0.840	81.0	0.827	83.5	0.810
74.0	0.850	81.5	0.845	74.0	0.840	82.5	0.835
65.0	0.855	78.5	0.830	69.2	0.840	81.0	0.840
54.5	0.920	73.0	0.870	67.0	0.850	76.0	0.820
52.5	0.935	71.0	0.880	54.0	0.924	75.5	0.825
46.0	0.955	62.5	0.920	50.5	0.975	71.5	0.850
37.8	1.000	57.0	0.925	44.0	1.005	68.0	0.855
31.8	1.080	53.2	0.940	40.0	1.040	62.5	0.898
25.0	1.145	49.0	0.980	35.5	1.074	59.8	0.910
		43.5	1.024	28.6	1.140	52.5	0.945
		39.0	1.040			49.0	0.960
		36.0	1.080			41.5	1.040
		33.0	1.090			35.0	1.085
		26.3	1.175			30.2	1.155

Table 23. Viscosity of Myverol dispersed in water.

% Myverol							
0.000		0.02		0.05*		0.20**	
Temp. °C	Visc. cp	Temp. °C	Visc. cp	Temp. °C	Visc. cp	Temp. °C	Visc. cp
78.5	0.820	78.3	0.770	70.6	0.840	83.0	0.835
74.0	0.850	70.0	0.820	64.8	0.845	80.8	0.830
65.0	0.855	63.8	0.825	55.0	0.895	76.9	0.840
52.5	0.938	56.0	0.870	48.6	0.955	73.8	0.860
48.5	0.945	47.0	0.920	43.0	0.985	72.0	0.875
47.2	0.970	41.0	0.970	38.6	1.023	67.0	0.890
37.8	1.000	36.6	1.040	35.8	1.070	57.0	0.940
32.2	1.045	34.8	1.040	33.8	1.080	39.8	1.075
31.8	1.080	32.2	1.050	32.3	1.090	34.5	1.140
26.5	1.130	31.2	1.060	31.8	1.105	30.8	1.180
25.0	1.145	30.3	1.070	26.8	1.155	30.4	1.195

* Some Myverol coalesced and separated out when cooled.

** Most of Myverol coalesced and floated to the top when cooled. Sometimes it badly interfered with the viscosity measurement at low temperatures. Special care was taken so that the Myverol globules did not come in contact with the spindle when the viscosity was being measured.

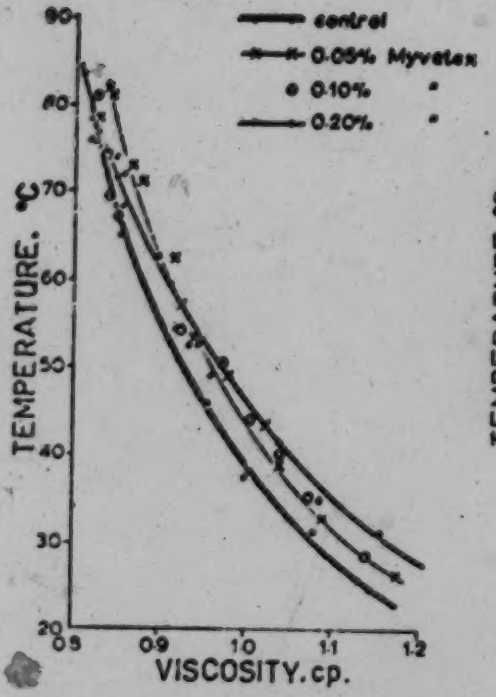


Figure 31. Viscosity* of Myvatex in distilled water.

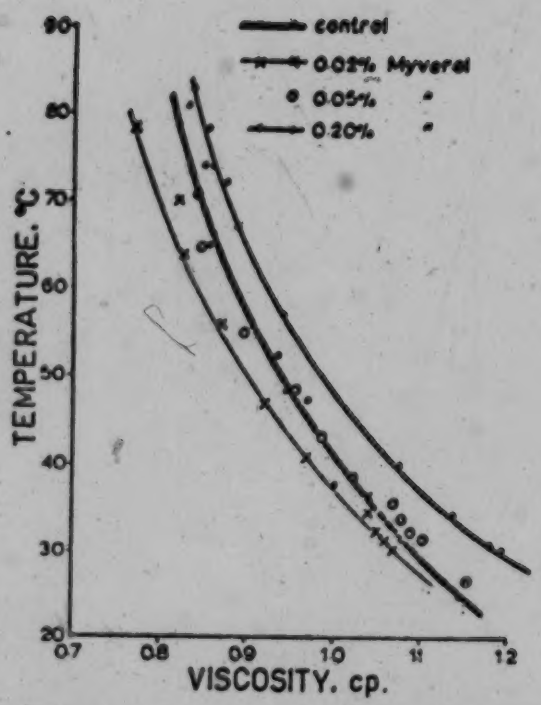


Figure 32. Viscosity* of Myverol in distilled water.

* The viscosity was measured using Brookfield Synchro-Lectric Viscometer Model RVT with the spindle No. 1 and the speed of 100 rpm.

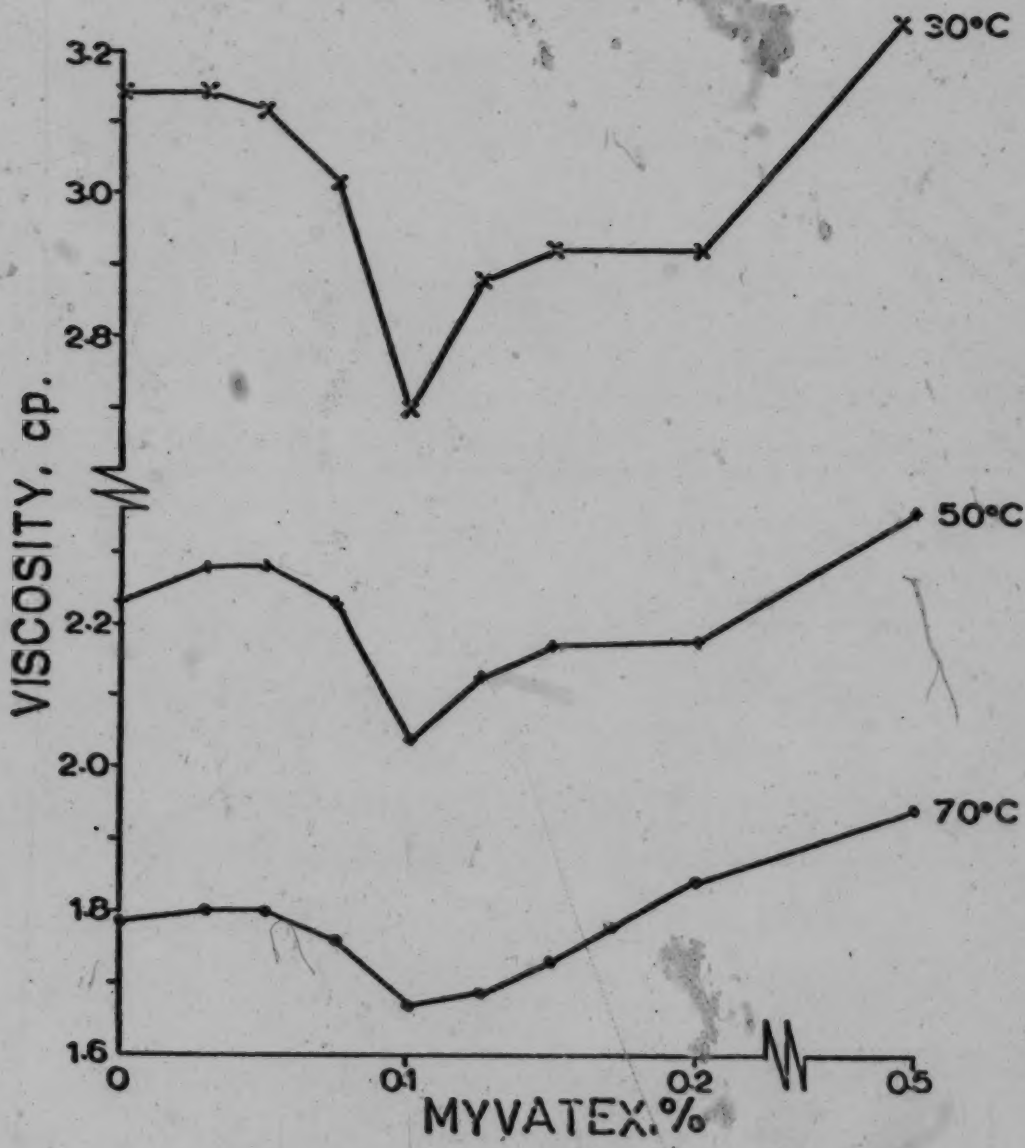


Figure 33. Effect of Myvatex concentration on viscosity of pectin solution at various temperatures.

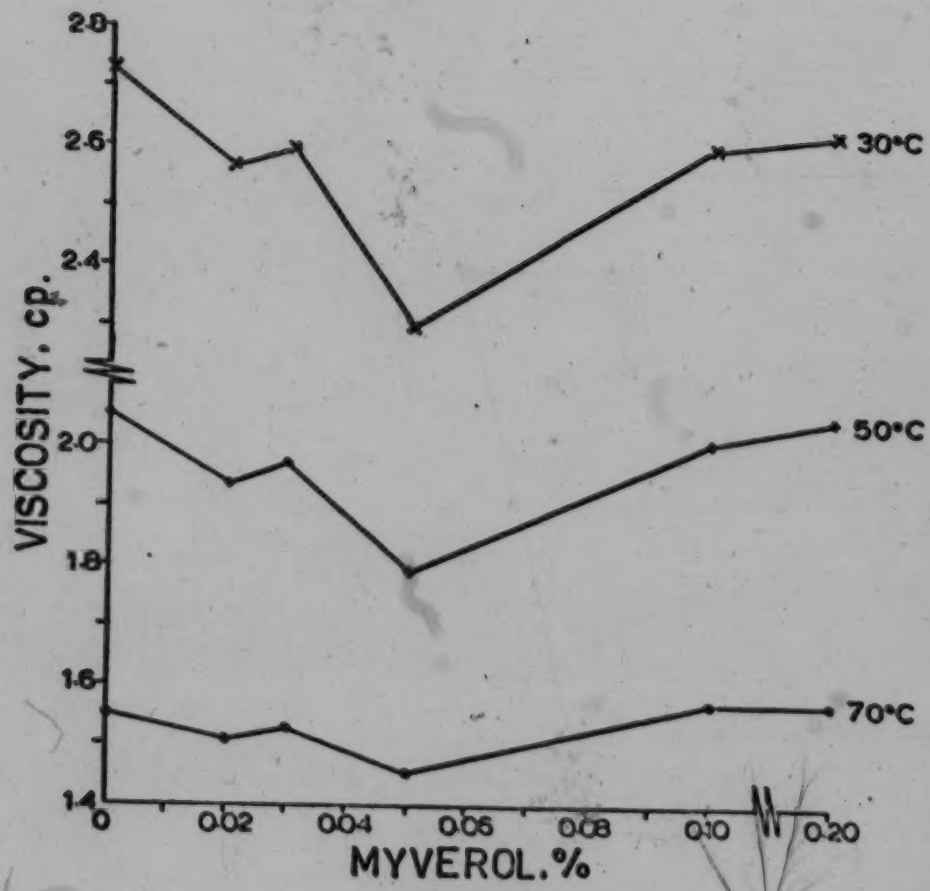


Figure 34. Effect of Myverol concentration on viscosity of pectin solution at various temperatures.

what has been shown in the case of starch, Myverol appears to be more effective as a pectin complexer, as a lower quantity is needed to give a lower minimum viscosity in pectin solution than does Myvatex (Figures 33 and 34). This may be due to the differences in HLB as well as in molecular size and configuration.

These data would suggest that it may be appropriate to use a mixture of a minimum of 0.2% Myvatex and a minimum of 0.05% Myverol, based on cooked potato weight, as a more effective combination of surfactants in potato granule production, than 0.2% Myvatex alone.

V. ESTIMATION OF SURFACE HEAT TRANSFER COEFFICIENTS IN AIR-BLAST FREEZING OF COOKED, MASHED POTATOES

The physical property data used in the freezing rate experiments are shown in Table 24. The freezing point agrees with that of Anderson (1959) but the density of the mashed potatoes is slightly greater than the density of raw potatoes on which his measurements are based. The thermal conductivity data and the latent heat are calculated from the equations given by Earle (1966).

Table 25 and Figure 35 show that the surface heat transfer coefficient (hs) of mashed potatoes is lower for larger cubes than it is for smaller cubes. Extrapolation of the hs vs size graph to small cubes gives hs = 6.27 Btu/ft^2

Table 24. Physical characteristics of mashed potatoes.

% Moisture, P	Density, ρ lb/cu ft	Latent Heat, λ Btu/lb	Thermal Conductivity, k Btu/ft h °F		Freezing Point, °F
			Above Freezing	Below Freezing	
77.6	62.8	111.8	0.282	1.120	30°

Table 25. Total surface heat transfer coefficients (hs) of mashed potato cubes.

Dimension of cube (in)	Volume of cube (ft^3)	ta* °F	Observed Freezing Time, hour	Calculated hs Btu/ft^2 h °F
1.00	0.578×10^{-3}	-10°	0.600	4.437
1.50	1.953×10^{-3}	-10°	1.100	3.707
2.00	4.657×10^{-3}	-19°	1.167	3.901
2.25	6.592×10^{-3}	-10°	1.750	3.586
2.75	12.040×10^{-3}	-19°	1.917	3.337
3.00	15.625×10^{-3}	-10°	2.383	2.976
4.00	36.926×10^{-3}	-10°	4.000	2.395
5.00	72.355×10^{-3}	-14°	5.833	2.307

* ta = air temperature in the freezer.

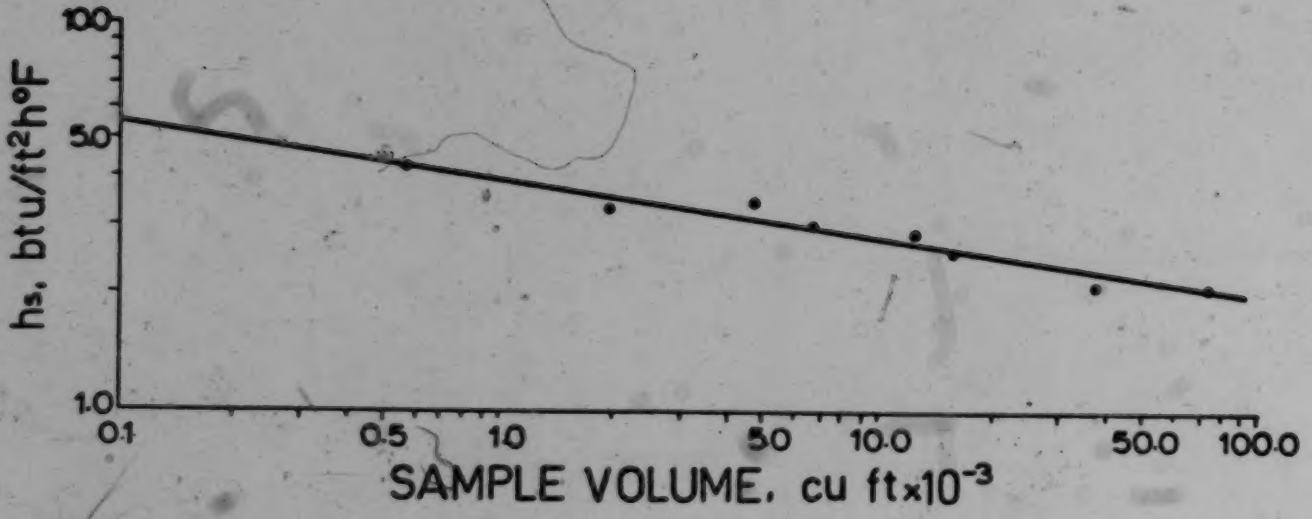


Figure 35. Surface heat transfer coefficients of cubes of mashed potatoes in air-blast freezer, with air velocity of 3,000 cu ft/min.

h °F, and a freezing time of only about 6 minutes for a 1/4 cu in cube.

If the surface heat transfer coefficients observed in these experiments can be used as approximate values for other shapes of mashed potatoes under similar conditions, then approximate freezing times can be calculated. For example, a layer of mashed potatoes 1/4 in thich will take approximately 18 minutes to freeze, with the surface heat transfer coefficient being the factor controlling the rate of freezing rather than conduction of heat from the advancing ice face through the layer of frozen material to the surface.

Further data will of course be required for detailed design of a freezing system; the freezing times calculated from these experiments do indicate that a continuous belt in a blast freezer tunnel is probably practicable.

In thawing of the frozen potatoes the process is the reverse of freezing (Ede, 1949). That is, to thaw a slab of 1/4 in. thick with initial temperature of 30°F in a thawing tunnel whose air temperature is about 70°F and air velocity is about 3,000 cu ft/min, should take approximately 18 minutes. With a higher air temperature and/or air velocity it should, of course, take less time.

Thus, it is believed that both freezing and

thawing of mashed potatoes can be a continuous process using continuous freezing and thawing tunnels. The size and capacity of these tunnels can be approximately estimated using the physical properties of mashed potatoes obtained in this experiment.

The thawing must be complete before proceeding to the next step, i.e. pre-drying in a stirred-bed fluidizer, otherwise it will not be possible to stir and dry the potatoes uniformly. Unnecessary cell damage may occur if the incompletely thawed potatoes are processed further due to the breaking of the frozen mass and shearing of the soft cells against the rigid ice crystals. Once thawed, however, the potatoes should pass to the next processing step immediately to avoid undue raising of temperature which may result in reabsorption of the released water back into the cells as observed by Greene et al. (1948). This reabsorption of moisture into the cells has a deleterious effect on the pre-drying and granulation steps of the present process as was discovered when the material was allowed to stand for an extended period of time after thawing. Among other effects, the drying rate was lower than similar runs which were pre-dried soon after thawing, and the material was distinctly less easy to handle. Also, microbial contamination and growth, as well as undesirable chemical changes, may occur if the delays are unduly long.

VI. PRE-DRYING, GRANULATION, DRYING, COOLING, AND PRODUCT CHARACTERISTICS

1. Pre-drying, granulation, drying, and cooling

A good many trial runs were done with the fluidized-bed dryer before the present modifications of the equipment were effected and the ideal conditions for the processing were obtained. Data from these runs are not reported here due to their multiplicity and complexity. The results reported in Tables 26, 27, 28, 29, and 30 are those obtained under ideal or near ideal conditions with the present equipment.

It should be noted that in all cases in pre-drying, the drying conditions were set such that the drying rate was at maximum. This was accomplished by high drying air temperature and high air velocity while the potatoes were slowly stirred at about 20 rpm. The heat and mass transfer rates in the bed were sufficiently high sc that the temperature of the potatoes was kept low, i.e. around room temperature or lower. This is so that the benefit rendered by the freeze-thaw technique is not lost by water reabsorption by the cells as would occur if the temperature was higher.

Towards the end of pre-drying, the moisture content of the potatoes enters the critical range of 45-35%. This could be visually determined by the fact that at this stage most of the potato is suspended in the air stream at

Table 26. Processing conditions of Run No. 1 using Netted Gem potatoes with S.G. 1.095. Wet load = 6.74 lb.

Processing Step	Processing Time, min	Drying Air Temp., °F Below Bed	Drying Air Temp., °F Above Bed	Air Mass Flow Rate lb/min	Air Velocity ft/min	Stirrer Speed, rps	Drying Rate, lb water/min	Product Moisture, % Observed	Product Moisture, % Calculated
Pre-drying	0	99	77	16.47	373.2	20	0.0892	76.13	-
	2	121	81	"	"	"	0.1551		
	4	130	87	"	"	"	0.1633		
	6	140	91	"	"	"	0.1910		
	8	146	89	"	"	"	0.2123		
	10	148	86	"	"	"	0.2351		
	12	150	84	"	"	"	0.2482		
	14	152	84	"	"	"	0.2547		
	16	152	84	"	"	"	0.2547		
	18	155	85.5	"	"	"	0.2482		
	20	140.5	84	16.33	370.0	"	0.2023		
Granulation	21	137.5	87.5	7.75	175.6	685	0.0846	-	46.25
	22	133	87.5	"	"	"	0.0769		
	23	128	86	"	"	"	0.0692		
	24	122.5	82.5	8.61	195.2	"	0.0743		
	24.5	120	84	"	"	"	0.0692		
	25	125	86	11.38	257.8	"	0.1015		
	26	133	104	16.65	377.3	"	0.1106		
Drying	28	164	149	"	"	0	0.0578	-	38.65
	30	197	177	10.23	231.7	"	0.0406		
	31	198	183	"	"	"	0.0345		
	32	202	195.5	7.17	162.5	"	0.0071		
	33	206	202.5	"	"	"	0.0071		
Cooling	34	188	194	4.13	93.6	"	0		
	36	160	178	"	"	"	"		
	38	148	160	"	"	"	"		
	40	135	145	"	"	"	"	5.29	-

Table 27. Processing conditions of Run No. 2 using Batted Gem potatoes with S.G. 1.095. Wet load = 7.50 lb.

Processing Step	Processing Time, min	Drying Air Temp., °F Below Bed	Drying Air Temp., °F Above Bed	Air Mass Flow Rate lb/min	Air Velocity ft/min	Stirrer Speed, rpm	Drying Rate, lb water/min	Product Moisture, % Observed	Product Moisture, % Calculated
Pre-drying	0	150	100	15.58	352.9	20	0.1836	76.13	-
	2	140	89	"	"	"	0.1774		
	4	136	83	"	"	"	0.1882		
	8	135	79	15.83	358.6	"	0.1976		
	12	136	78	"	"	"	0.2133		
	16	136	78	"	"	"	0.2133		
	18	136	78	16.12	365.1	"	0.2171		
	19	136	78	"	"	"	0.2171		
	20	126.5	76.5	"	"	"	0.1884		
	22	126.5	80.5	"	"	"	0.1692		
Granulation	22.5	126.5	82	1.36	30.9	485	0.0395	-	44.25
	23.5	127.5	84	"	"	"	0.0395	37.75	43.90
	25	127	87	"	"	"	0.0076		
	26	123	85	"	"	"	0.0079		
	27.5	126	84	2.14	48.4	"	0.0207		
Drying	28.5	131	86	10.59	239.9	0	0.1112		
	30	135	89	"	"	"	0.1133	26.70	36.20
	31.5	138	120	16.44	372.4	"	0.0716		
	33.5	150	142	10.05	227.7	"	0.0398		
	36	179	171	"	"	"	0.0169		
	37	183	178.5	"	"	"	0.0080		
	38	180	180	"	"	"	0		
Cooling	39	175.5	175.5	1.36	30.9	"	"		
	42.5	138	146	1.11	25.2	"	"		
	44	128.5	136	"	"	"	"		
	45	-	-	"	"	"	"	5.35	-

Table 28. Processing conditions of Run No. 3 using Netted Gem potatoes with S.G. 1.095. Freshly thawed potatoes = 4.32 lb. Recycled coarse fractions from previous runs = 0.48 lb.

Processing Step	Processing Time, min	Drying Air Temp., °F Below Bed	Drying Air Temp., °F Above Bed	Air Mass Flow Rate lb/min	Air Velocity ft/min	Stirrer Speed, rpm	Drying Rate, lb water/min	Product Moisture, % Observed	Product Moisture, % Calculated
Pre-drying	0	154	93	16.48	372.4	20	0.2313	68.55	-
	2	139.5	82	"	"	"	0.2134		
	4	138	80	"	"	"	0.2134		
	6	138	79.5	16.94	383.8	"	0.2199		
	7.5	137	80.5	"	"	"	0.2132		
	9	124.5	80	"	"	"	0.1695		
Granulation	11	125	80	1.65	37.4	485	0.0094	42.49	43.70
	12	124	88.5	"	"	"	0.0058		
	12.5	123	89	2.08	47.2	"	0.0073		
	15	117	87	12.81	290.3	"	0.0476		
Drying	16	115	89	11.92	270.0	0	0.0708	-	41.30
	17	113	94	"	"	"	0.0531		
	18	145	114	"	"	"	0.0803		
	20	176	167	15.79	357.8	"	0.0360		
	22	187	185.5	"	"	"	0.0047		
	23	193	191	8.36	189.5	"	0.0041		
	23.5	195	195	"	"	"	0		
	24	189	198	"	"	"	"		
Cooling	25	182	191	1.00	22.8	"	"		
	28	146	162	"	"	"	"		
	32.5	120	133.5	"	"	"	"	3.72	-

Table 29. Processing conditions of Run No. 4 using Wetted Gem potatoes with S.G 1.080. Wet load = 9.42 lb.

Processing Step	Processing Time, min	Drying Air Temp., °F Below Bed	Drying Air Temp., °F Above Bed	Air Mass Flow Rate lb/min	Air Velocity ft/min	Stirrer Speed, rpm	Drying Rate, lb water/min	Product Moisture, % Observed	Product Moisture, % Calculated
Pre-drying	0	156	111	15.33	347.2	20	0.1685	80.90	-
	4	134	84.5	"	"	"	0.1715		
	8	140	88	"	"	"	0.1836		
	12	142	89	"	"	"	0.1467		
	16	144	93	"	"	"	0.1436		
	20	147	95.5	"	"	"	0.1821		
	22	147	93	14.86	336.6	"	0.1461		
	28	146	85	"	"	"	0.2090		
	32	145	84	"	"	"	0.2100		
	33	145	83.5	"	"	"	0.2104		
	34	130	81.5	"	"	"	0.1663		
	35	133	79.5	"	"	"	0.1854		
	36	117.5	77	15.90	360.2	"	0.1430		
	37	100	75	"	"	"	0.0882	41.84	39.80
Granulation	38	122	80	1.65	37.4	485	0.0143	-	37.20
	44	124	85	"	"	"	0.0126		
	45	122	88	9.94	225.2	"	0.0798		
	47	118	86	11.56	261.8	"	0.0347		
Drying	48.5	114	80	"	"	0	0.0004	25.11	26.90
	50	131	84	13.50	305.7	"	0.1497		
	51	143	87	"	"	"	0.1724		
	52	148	104	15.54	352.1	"	0.1447		
	53	140	124	11.09	251.3	"	0.0417		
	56	153	144	1.54	35.0	"	0.0037		
	62	175	161	"	"	"	0.0049		
Cooling	64	178	171	1.07	24.2	"	0.0021		
	65	168	168	"	"	"	0		
	68	144	152	"	"	"	"		
	75	117.5	127.5	"	"	"	"	5.47	-

Table 30. Processing conditions of Run No. 5 using Wetted Gem potatoes with S.G. 1.080. Freshly thawed potatoes = 10.37 lb. Recycled coarse fractions from previous run = 0.41 lb.

Processing Step	Processing Time, min	Drying Air Temp., °F Below Bed	Drying Air Temp., °F Above Bed	Air Mass Flow Rate lb/min	Air Velocity ft/min	Stirrer Speed, rpm	Drying Rate, lb water/min	Product Moisture, % Observed	Product Moisture, % Calculated
Pre-drying	0	184	100	14.32	324.4	20	0.2651	77.56	-
	2	152	90.5	"	"	"	0.2049		
	6	165	96	"	"	"	0.2340		
	10	170	94	"	"	"	0.2397		
	15	174	93.5	14.07	318.8	"	0.2619		
	22	175	88.5	"	"	"	0.2415		
	28	174	88.5	"	"	"	0.2808	34.82	35.29
Granulation	30	138	82	1.51	34.1	485	0.1796	-	31.03
	35	138	85	"	"	"	0.0165		
	37	132	84	1.87	42.3	"	0.0209		
	39	122	79.5	11.23	254.5	"	0.1257	23.66	25.54
Drying	41	133	99	14.50	328.5	0	0.1134		
	42	138	110	15.82	349.4	"	0.1023		
	44	140	122	"	"	"	0.0641		
	46	140	133	15.25	345.6	"	0.0257		
	47	152	145	11.27	255.3	"	0.0212		
	49	156	149	1.54	35.0	"	0.0026		
	53.5	164	158	"	"	"	0.0023		
Cooling	55	158	156	"	"	"	0		
	57	140	147	1.04	23.6	"	"		
	60	126	135	"	"	"	"		
	63	116.5	124	"	"	"	"	2.76	2.89

the air velocity of about 330 ft/min If the process were continuous, consisting of separate units of a pre-dryer and a granulator, the suspended particles could be carried away in the air stream into the granulator for the subsequent granulation. In the present studies, however, the granulation was performed in the same unit of equipment as the pre-drying.

At this stage the drying air temperature was reduced to about room temperature and the air velocity was reduced from about 330 ft/min to about 30 ft/min. The drying rate at this stage dropped sharply to minimum. This is necessary as granulation can be accomplished quickly and efficiently at this stage by applying high compressive and shear forces through increasing the stirrer speed from 20 rpm to about 480-500 rpm while the moisture content is kept within the critical range. The granulation is accomplished within a short time of 5-10 minutes while the moisture content of the potatoes is slowly reduced through the critical range to normally slightly lower than 35%. If the granulation was terminated too soon, as in Run No. 3, and the potatoes entered drying step while still moist and not sufficiently granulated, the amount of the -60 mesh fraction in the product would be considerably reduced (Tables 28 and 31). On the other hand, if the granulation was initiated rather late, as in Run No. 5, when the moisture content of the potatoes was already passing through the lower end of

Table 31. Size distribution, bulk density, moisture content and percentage of broken cells in products from Runs 1 to 5.

Sample	Granule Size, %				Product Density, gm/cc	Product Moisture, %	Broken Cell, %
	+16 Mesh	+30 Mesh	+60 Mesh	-60 Mesh			
Run 1	1.15	1.72	14.35	82.78	0.83	5.29	0.8
Run 2	1.19	1.43	10.98	86.40	0.79	5.35	2.1
Run 3	0.93	3.21	23.00	72.86	0.79	3.72	1.7
Run 4	2.00	2.25	8.14	87.61	0.77	5.47	1.5
Run 5	1.81	4.80	20.92	72.47	0.77	2.76	1.3

the critical range, the result would also be a reduction in the -60 mesh fraction (Tables 30 and 31). The conditions in Run No. 2 and 4, where granulation began at the moisture content of about 42%, and carried on at the high stirrer speed for 6-10 minutes until the moisture was reduced to about 27%, would thus appear to be ideal for this process as the results of these runs were very high -60 mesh fractions.

At the end of the granulation step, when the stirrer was stopped, the temperature and the air velocity were again increased. It should be noted that towards the end of this step the air velocity was increased to about 220 ft/min at which all the sufficiently granulated particles were suspended in the air stream. As in the pre-drying step, if the process were continuous and the granulator and the dryer were separated the granules would be carried away in the air stream into the dryer.

In the drying step, the drying temperature was increased to about 200°F and the air velocity was increased to about 330 ft/min until the granules were almost being blown right out of the bed. This step normally takes 5-10 minutes and gives granules of approximately 12-15% moisture. The air velocity was then reduced to about 20 ft/min to avoid abrasive damage of the granules.

The final drying was complete about 5 minutes after the reduction in air velocity and was followed by

cooling of the granules to room temperature using an air velocity of about 20 ft/min.

2. Drying rates of potatoes

It should be noted, first of all, that the calculated results, i.e. air velocity, drying rate, and moisture contents, appear reliable. The calculated moisture content at various stages of processing in most cases (Tables 26, 27, 28, 29, and 30), for example, agrees within ± 3% of the observed values. The discrepancies, particularly in Run No. 2 however, resulted from the fact that when samples of the potatoes were taken for moisture analysis the drying chamber had to be opened and the collecting bag lifted to gain access to the product. Even though only a short period of time might elapse during the sample taking, the drying conditions e.g. air velocity, drying temperatures, were upset so that when the automatically recorded temperatures were interpreted for calculations, some errors which were not easy to allow for resulted. These, fortunately, were minor in most cases.

During drying, two main flow mechanisms assume major role in the movement of water in the material being dried (Van Arsdel, 1963). In granular solids such as sand, the physical unbalance of forces at the interface between a liquid and gas or vapor produces the effect of a suction on the liquid as that in the rise of a liquid in a capillary tube. Hence, in this type of material, capillary flow

mechanism controls the movement of water during drying at least in the early stages when the moisture is high. In the moist body with fine structure and in hygroscopic materials, on the other hand, the drying is governed by diffusional phenomena. This is the mechanism whereby the water in the body diffuses outward due to pressure and water concentration gradients. A diffusion resistance factor is characteristic of a material under a particular set of conditions. The diffusional transfer mechanism is also found to govern the late phases of drying in all cases whatever mechanisms the earlier phases are governed by.

The granular, non-hygroscopic materials exhibit two well defined phases during drying. The first phase is the constant-rate period where the evaporation rate remains constant as the rate of the transport of water from within the body to the surface is the same as the rate of evaporation of the water from the surface to the surrounding. When the material is dried to a certain moisture level, however, the rate of water transport within the body cannot keep up with the rate of evaporation from the surface, hence the rate of drying drops and the drying is said to enter the falling-rate period (Van Arsdel, 1963).

Earle (1966) states that many foods such as potatoes do not show a constant-rate period of drying, but they exhibit quite a sharp break after a slowly and steadily declining rate period. Saravacos and Charm (1962) reported

that most of the drying of fruits and vegetables takes place during the falling-rate period due to their colloidal and hydrophilic nature which causes the water molecules to be held more tightly. They found that the moisture content at the transition point between the constant-rate period and the falling-rate period (critical moisture content, Wc) is characteristic of each material for a given set of drying conditions. They found no significant effect of blanching on drying rate of potatoes, but found that higher air velocity increases drying rate in the constant-rate period but has no effect on the falling-rate period. They reported Wc of potatoes as 77.78% wet basis.

In the present studies, a long, well defined constant-rate period of potatoes was observed during pre-drying step (Figures 36, 37, 38, 39, and 40). In most cases the drying rates were somewhat lower at the beginning. This is due mainly tc the fact that the drying air temperature was low during the come-up time, and that some of the heat was spent in heating the potatoes up to the equilibrium temperature for the constant rate period. The constant-rate period continued until the granulation step when the rate dropped due to lower temperature and air flows. It is apparent that the drying enters the falling-rate period during the granulation step. With the extrapolation of the curves it would appear that the critical moisture content of the potatoes under these conditions is between 45-40% wet basis. This means that drying rate of potatoes under this

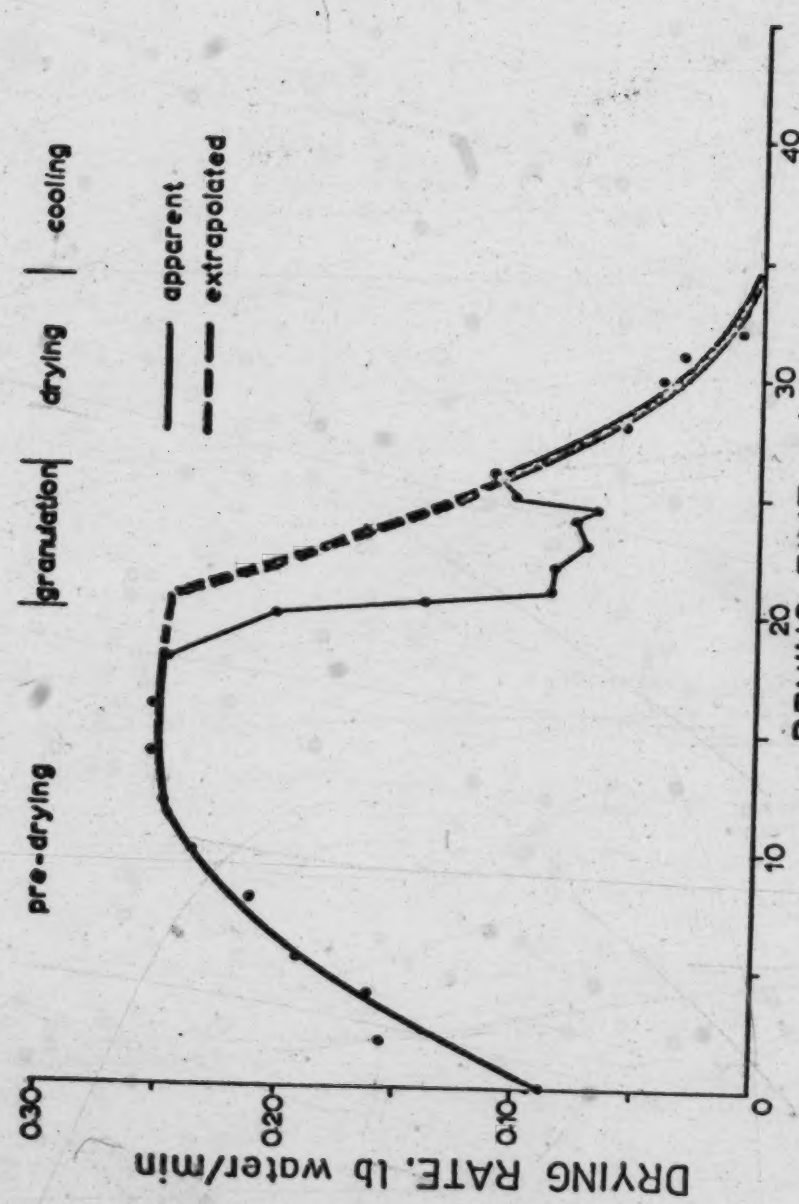


Figure 36. Drying curve for Run 1. Wet load = 6.74 lb.
Total solids = 1.64 lb.

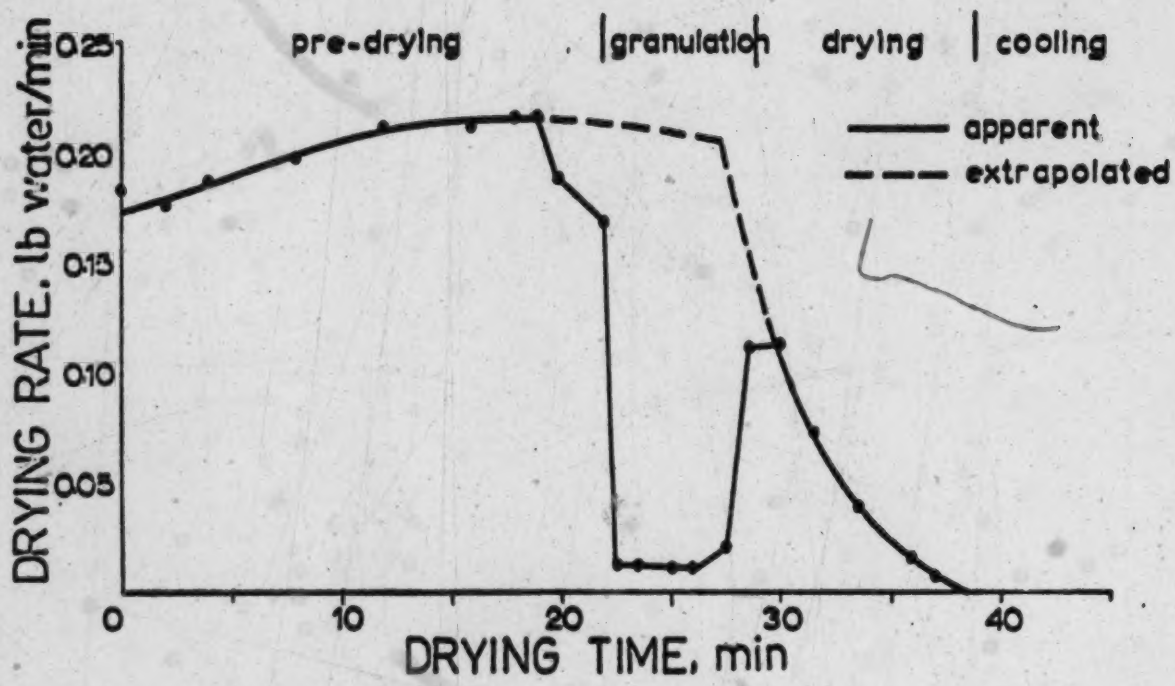


Figure 37. Drying curve for Run 2. Wet load = 7.5 lb.
Total solids = 1.8 lb.

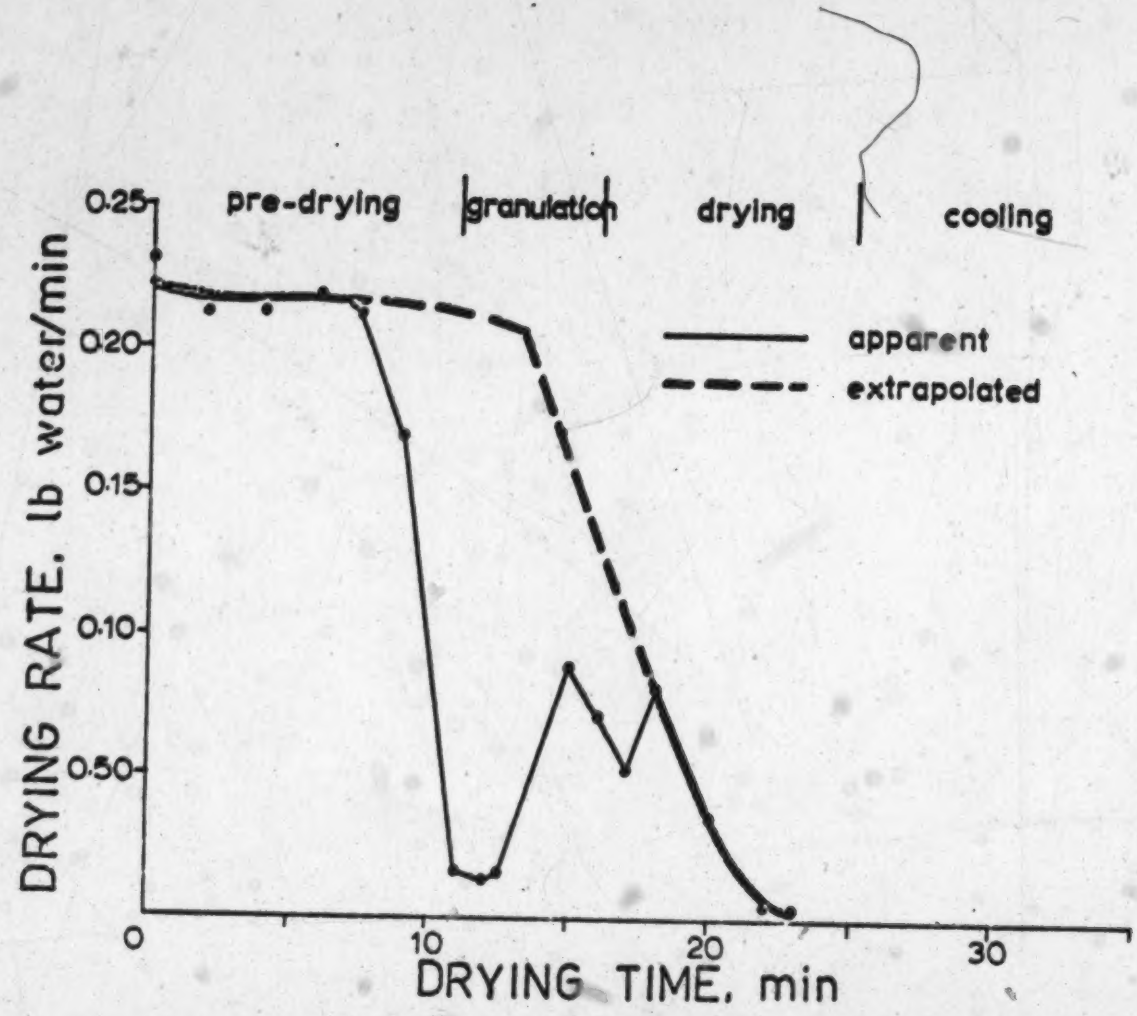


Figure 38. Drying curve for Run 3. Wet load = 4.8 lb.
Total solids = 1.5 lb.

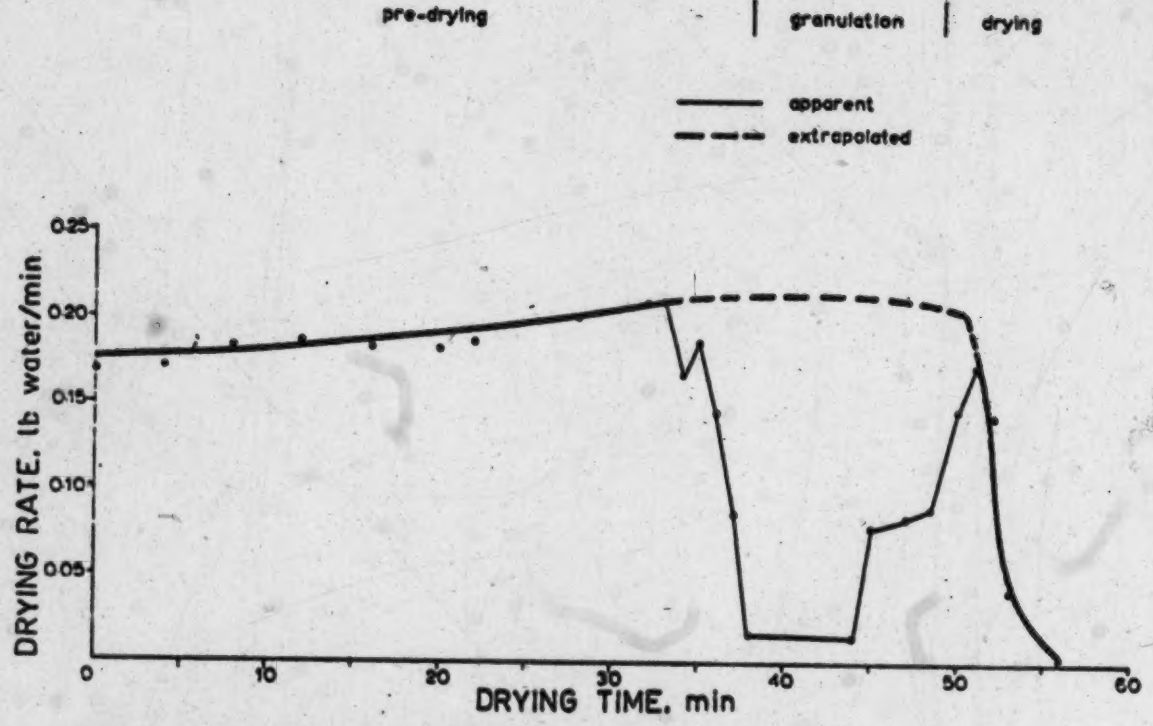


Figure 39. Drying curve for Run 4. Wet load = 9.42 lb.

Total solids = 1.81 lb.

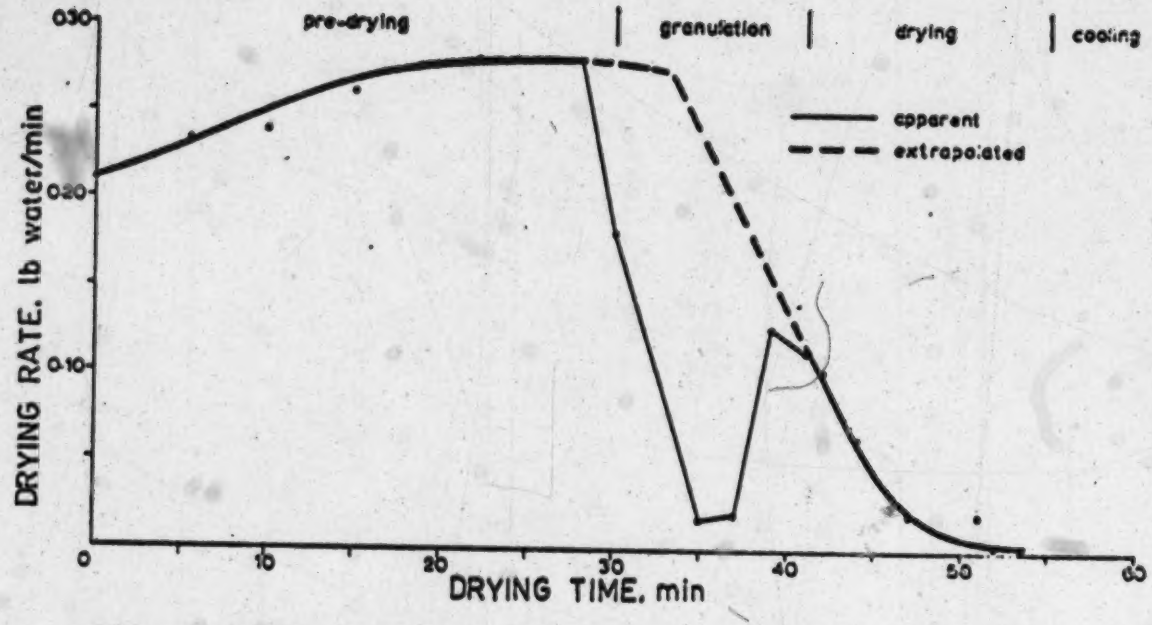


Figure 40. Drying curve for Run 5. Wet load = 10.8 lb.
Total solids = 2.4 lb.

process can be maintained at a maximum until the potatoes are dried to about 40% moisture. Hence, relatively rigorous drying conditions can be applied during this period to shorten the processing time, which means greater product output per unit time.

The lengthy constant-rate period can be attributed to the effects of freezing and thawing of the mashed potatoes. Freezing not only toughens the cell wall and precipitates the solubilized starch, but renders the potatoes much easier to dry. During freezing numerous ice crystals are formed and consequently a great part of water within the cells is drawn out into the extracellular interstices by osmotic pressure (Hall, 1953) and on thawing is available as free liquid outside the cells which can be easily evaporated. As the freezing process progresses most or all of the water will be transformed to tiny ice crystals many of which will form minute passages through the cell wall by physical puncturing of the wall. These passages are conceivably not big enough to allow the escape of the macromolecules from the cell, but are big enough to let water molecules pass through with relative ease during drying. The mashed potatoes after thawing have a very grainy appearance. As the cells are being continuously separated by the stirrer, the whole mass behaves in a manner similar to wet sand which is a material in which moisture movement is predominantly by capillary action in the early stages of

drying. Hence, it appears most likely that the major part of the water in the thawed mashed potatoes exists in the form of free or surface water, and that in the early phase of drying capillary mechanism plays an important role in the movement of water from the interstices between adhering potato cells to the surface at which drying is taking place.

3. Product characteristics

It is apparent from Table 31 that the process under investigation is capable of producing a high quality product. The broken cell count is quite low. In five runs, the product from Run No. 2 has the highest broken cell count (2.1%) which is low as compared to 3-6% obtained with direct processing technique described by Lazar et al. (1964). The product bulk density is reasonably high with bulk densities as high as 0.91 gm/cc being obtained in several trial runs. The process is also capable of producing a very high percentage of fine granules (i.e. -60 mesh). It is believed that with more efficient equipment and more effectively controlled process, over 90% of -60 mesh granules could be regularly achieved in the output.

The quantity of oversize (i.e. +16 mesh) material (which is discarded) is also low, with the maximum value of 2% occurring in Run No. 4. The average percentage of +16 mesh granules for the five runs is 1.41%, which is significantly lower than the 5% oversize reported by Lazar and coworkers. In fact, the oversize material was very

frequently less than 1% in the trial runs which have not been reported in detail. It would appear that a major factor that controls the size of this fraction is the initial moisture content of the potatoes. In Runs 4 and 5 the potatoes had dry matter content of about 19% as compared to about 24% dry matter in Runs 1, 2, and 3. In Run No. 4, the thawed, mashed potatoes were rather wet and the material was more difficult than usual to handle in the pre-drying step. This resulted in a considerably longer time being taken for this step (Figure 39). The wetter potatoes are more susceptible to forming a thin film on the surfaces of the fluidizing bowl and the stirrer during pre-drying, resulting in the unusually high discard as reported. This problem is easily corrected by adding the coarse fractions, i.e. those between 16 and 60 mesh, from the previous run to the thawed potatoes prior to pre-drying to absorb the excessive amounts of surface moisture. The results in Run No. 4, nevertheless, has shown that the process is capable of handling the potatoes with low specific gravities, which are not generally considered processable with other techniques.

Recycling of the coarse particles poses no observable problem in this process. The intermediate size particles (-16 mesh, +60 mesh) account for only a little higher than 10% of the total output, and may be possible to lower this quite considerably with more efficient processing equipment. The adding of these fractions, prior to or during

pre-drying, to the freshly thawed potatoes will in fact benefit the process by rendering the mix easier to handle and thus further shorten the pre-drying time. No undesirable characteristics carried over by the recycled particles to the successive batch of product were experienced in the present investigations.

It was observed during the trial runs also that "immature" potatoes were unsuitable for processing of potato granules due to high proportions of broken cells they produced. This may be due to the fact that when they were harvested the potato tissue had not been fully developed resulting in weak cell walls which could not withstand forces during processing. Preliminary study showed that if such potatoes were stored at 42°F for at least one month, or if they were sprayed with ethrel (2-chloroethyl phosphonic acid) and stored at the same temperature for at least one week, they could then produce a satisfactory product. Ethrel is a chemical which evolves ethylene gas (Warner and Leopold, 1969; Yang, 1969) which is a volatile normally used to hasten the ripening process of climacteric fruits.

The moisture content of the product in most cases was just over 5% which is considered ideal for dehydrated potato products (Strolle and Cording, Jr., 1965). The level of moisture content of the product can, however, be easily controlled by adjusting the time and/or temperature during drying and cooling steps, if this is necessary.

Another desirable characteristic of the product obtained with this process is its consistent ability to reabsorb water, either hot or cold, on reconstitution. It was found that regardless of the variation in the specific gravity of the potatoes used, the products always exhibited the same consistency on reconstitution with the same ratio of product to water. The product to boiling water ratio was consistently found to be 1:4 (w/v) for dry and firm reconstituted mashed potatoes, and can take up to 1:5 (w/v) for a softer product. This reabsorption is greater than for the commercial granules used in the texture evaluation tests, which gave a comparable product with a 1:3.2 ratio, and a soft product with the 1:4 reconstitution ratio.

The higher water absorptivity can again be attributed to the effects of the freeze-thaw treatment on the mashed potatoes in the proposed technique. It may be due to the fact that after the freeze-thaw step the cell wall is probably more porous, as suggested in Section C. VI. 2., hence on reconstitution it allows water to diffuse through more readily.

The lower quantities of granules used per unit quantity of reconstituted product will effect significant economies to the consumer whether in the home or in an institutional kitchen. Further, the reabsorption ratio is much more uniform than that obtained at times by the add-back process. This will have important ramifications in

marketing at both the institutional and retail levels.

VII. PRODUCT QUALITY

1. Texture panel tests

It is apparent from Table 32 that the product produced through the method under investigation has a water reabsorption capability comparable to that of potato flakes, i.e. the product to boiling water ratio (w/v) is 1:4. The commercial granules produced through the add-back method, on the other hand, absorb less water for a comparable product with the ratio being only 1:3.2.

The results of the first set of texture evaluation of the mashed potato samples are shown in Table 33. The statistical analysis of the overall characteristic of the samples in the first set of the texture panel results (Table 34) shows that the difference among judges is highly significant. The interaction between sample and judge is also highly significant. These may be interpreted that not only the samples differ widely from one another in their textural characteristics, but that the judges also differ greatly in their preference towards textural quality of mashed potatoes. Nevertheless, the first set of the tests served its purpose to familiarize the panelists with the range of the samples and the textural qualities to be judged.

Table 32. Reconstitution ratios of dehydrated mashed potato samples.

Sample*	Reconstitution Ratio Product : Boiling Water (w/v)
Ex. I	1 : 4
Ex. II	1 : 4
Com. I	1 : 3.2
Com. II	1 : 4

* Ex. I is a typical product obtained from the proposed freeze-thaw process.

Ex. II is a specially processed product which gives a very gluey texture on reconstitution.

Com. I is a commercial potato granule product obtained from a local supermarket.

Com. II is a commercial potato flake product obtained from a local supermarket.

Table 33. Transformed results of the first series of texture panels.

Judge No.	Sample	Characteristic: Firmness				Smoothness				Gluyness				Overall			
		Day: 1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	Ex. I	2	3	2	3	5	4	4	3	5	4	5	2	5	4	4	2
	Ex. II	4	3	3	2	3	4	3	5	2	4	3	5	1	4	2	4
	Control	4	3	3	3	1	3	3	3	4	3	2	2	1	2	2	2
	Con. II	2	2	2	2	5	5	4	5	5	5	5	5	5	5	4	4
	Con. I	2	2	2	2	4	5	4	5	5	5	5	5	4	5	4	4
2	Ex. I	4	3	3	4	3	3	4	4	5	4	4	4	3	2	2	2
	Ex. II	1	5	3	3	5	5	5	5	1	2	2	3	1	1	1	1
	Control	4	4	5	4	3	3	3	3	5	5	2	4	2	4	2	3
	Con. II	3	3	4	3	5	4	3	3	5	3	5	3	2	2	3	3
	Con. I	4	4	2	3	3	2	5	3	3	4	4	4	3	3	1	2
3	Ex. I	1	2	3	5	5	4	2	4	5	5	5	2	2	4	2	2
	Ex. II	2	2	2	5	5	5	5	5	5	5	5	1	4	4	3	1
	Control	4	5	5	4	4	3	3	4	5	3	2	2	4	5	2	3
	Con. II	4	2	4	3	4	5	3	4	5	5	5	4	5	5	4	4
	Con. I	3	5	1	4	3	2	5	2	2	2	5	5	1	1	1	3
4	Ex. I	2	3	2	2	3	3	3	3	3	4	5	4	2	2	2	3
	Ex. II	2	3	2	2	4	3	4	3	3	3	4	2	1	2	1	1
	Control	3	3	3	3	3	3	3	3	4	5	5	4	3	4	3	4
	Con. II	3	3	3	3	4	3	3	2	4	5	5	5	4	3	2	2
	Con. I	2	2	2	2	3	4	3	2	5	5	5	5	2	1	2	1
5	Ex. I	2	2	2	3	4	4	4	4	3	5	5	5	3	4	3	4
	Ex. II	2	2	4	2	4	4	4	4	2	5	4	5	3	4	3	3
	Control	3	3	2	3	4	3	4	4	4	5	5	4	3	4	3	4
	Con. II	3	2	3	4	3	3	3	4	5	4	5	4	3	2	3	3
	Con. I	3	3	3	3	3	3	3	3	4	5	5	5	4	1	1	1
6	Ex. I	2	2	2	3	3	3	3	3	5	4	5	4	4	3	3	2
	Ex. II	2	3	3	4	4	4	4	5	2	3	3	2	1	2	2	1
	Control	2	3	3	4	3	3	2	2	3	5	3	4	3	3	4	3
	Con. II	3	2	2	3	4	4	2	4	4	4	4	4	2	2	3	3
	Con. I	1	3	2	3	2	2	3	2	4	4	4	5	4	4	4	4
7	Ex. I	3	3	3	3	3	3	3	3	4	4	3	3	3	3	2	3
	Ex. II	5	1	1	1	4	5	5	5	1	2	1	1	1	1	1	1
	Control	4	4	2	4	3	2	3	4	5	5	3	4	3	3	2	2
	Con. II	5	2	4	4	2	3	2	2	5	4	5	5	2	2	4	4
	Con. I	4	4	3	4	4	3	4	4	5	5	4	2	2	4	3	3
8	Ex. I	2	3	2	3	4	3	4	4	5	5	4	4	4	3	3	2
	Ex. II	2	4	3	3	4	4	5	4	2	1	1	2	2	1	1	1
	Control	3	4	3	3	3	4	4	3	5	2	2	3	3	1	2	2
	Con. II	4	4	2	2	4	4	4	3	2	4	5	5	1	3	4	3
	Con. I	3	3	2	3	4	4	5	5	2	3	4	3	2	2	4	3
9	Ex. I	3	1	3	4	3	5	5	5	4	5	5	4	2	4	4	3
	Ex. II	4	4	3	3	4	4	5	4	5	2	2	3	2	2	1	1
	Control	3	2	4	4	3	3	4	3	3	5	4	3	3	3	2	1
	Con. II	2	3	3	5	4	4	4	4	4	3	4	5	3	3	2	1
	Con. I	3	1	3	4	3	4	5	4	5	4	5	5	3	1	2	4
10	Ex. I	2	3	3	1	5	4	4	5	5	5	5	5	3	4	4	2
	Ex. II	4	5	4	5	4	4	1	3	1	4	1	1	5	5	4	4
	Control	5	4	1	2	4	3	2	2	3	4	4	4	2	2	1	1
	Con. II	2	4	3	1	4	4	4	3	1	2	4	5	2	1	2	2
	Con. I	2	2	2	1	4	4	4	4	5	5	5	5	5	4	4	5

Table 34. Analysis of variance of the overall characteristic of the samples from the first set of texture panel results.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio	Probability Level
Day	3	4.335	1.445	2.2055	0.100
Sample	4	45.6	11.4	17.3997	<<0.005
Judge	9	36.525	4.0583	6.1942	<<0.005
Day x Sample	12	8.24	0.6867	1.0480	0.100
Day x Judge	27	11.415	0.4228	0.6453	not significant
Sample x Judge	36	115	3.1944	4.8756	<<0.005
Day x Sample x Judge	108	70.76	0.6552	1	
Total	199	291.875	0	0	

Table 35. Variance ratios of individual judges based on their judgment of the overall characteristic from the first set of texture panel results.

Judge No.	Source of Variation	Variance Ratio	Probability Level
1	Day	0.8276	>>0.100
	Sample	5.3793	<0.025
2	Day	0.6032	>>0.100
	Sample	3.4762	0.050
3	Day	2.0000	>0.100
	Sample	5.0000	<0.025
4	Day	0.3859	>>0.100
	Sample	7.1053	<0.005
5	Day	0.5454	>>0.100
	Sample	6.5454	0.005
6	Day	1.0000	>>0.100
	Sample	10.8947	<0.005
7	Day	0.3056	>>0.100
	Sample	4.6667	0.025
8	Day	0.3137	>>0.100
	Sample	1.8235	>0.100
9	Day	0.6667	>>0.100
	Sample	3.5143	0.050
10	Day	0.8276	>>0.100
	Sample	37.5517	<<0.005

In an attempt to screen the panelists for the second set of tests, variance ratios of individual judges were computed based on their judgment on the overall characteristic. It appears (Table 35) that none of the judges show significant variation in their judging ability from day to day. Judge No. 3, however, produced the highest "Day" variance ratio of 2.00. Though this is not quite significant at the 0.10 probability level, the variance ratio was considerably greater than that of any other judge. Judge No. 3 was therefore not included in the panel for the second set of texture evaluations.

With the comments from some panel members in the first set of the tests that the five-point scale for each characteristic was too narrow for accurate differentiation of the samples, the scale was expanded to nine in the second set of tests. In this set the judges simply inserted numbers from 1 to 9, as the case may be, directly for each characteristic instead of crossing an appropriate box as in the first set. In this way differences among samples were more clearly shown, and the results could be analysed directly without further transformation. One disadvantage of the nine-point scale, however, is the difference in the tendency of each panelist to judge low or high. Some panelists are more liberal than the others in scoring, so their scores may be on the high end of the scale, while the more conservative ones may prefer the low end of the scale.

Table 36. Results of the second series of the texture panels.

Judge No.	Sample	Characteristic: Firmness (Day 1)	Firmness (Day 2)	Firmness (Day 3)	Firmness (Day 4)	Smoothness (Day 1)	Smoothness (Day 2)	Smoothness (Day 3)	Smoothness (Day 4)	Glueyness (Day 1)	Glueyness (Day 2)	Glueyness (Day 3)	Glueyness (Day 4)	Overall (Day 1)	Overall (Day 2)	Overall (Day 3)	Overall (Day 4)
1	Ex. I	7	7	8	9	8	8	7	8	6	7	5	7	6	5	5	5
	Ex. II	7	7	7	7	8	9	9	9	9	3	3	1	2	3	4	3
	Control	9	9	8	8	7	7	7	7	8	6	7	5	3	4	4	4
	Con. I	6	7	8	7	9	9	8	9	9	9	8	9	8	6	7	7
	Con. II	2	9	7	7	9	8	9	8	9	9	9	6	7	7	7	5
2	Ex. I	8	8	2	3	8	8	9	8	9	9	8	7	8	8	8	7
	Ex. II	8	9	9	3	2	4	2	5	1	1	1	4	1	3	2	4
	Control	7	3	7	9	4	8	7	3	6	7	8	4	5	7	7	5
	Con. I	4	4	7	6	6	6	6	7	5	6	5	5	2	5	4	6
	Con. II	5	7	7	8	4	7	7	7	4	7	5	4	4	7	6	6
3	Ex. I	7	5	6	7	7	6	5	4	4	5	5	7	4	3	5	6
	Ex. II	3	8	2	4	9	8	9	8	1	1	1	1	3	4	2	3
	Control	8	8	7	5	8	7	4	5	7	3	7	2	5	5	5	2
	Con. I	5	7	5	6	3	5	5	3	7	7	8	8	7	6	6	7
	Con. II	6	6	4	8	7	3	3	5	5	8	9	9	6	7	7	8
4	Ex. I	2	3	6	5	7	4	3	3	8	3	3	3	7	5	7	5
	Ex. II	5	2	7	3	6	7	7	4	4	3	2	5	5	5	4	5
	Control	3	3	7	6	6	7	3	4	9	5	7	3	7	7	8	5
	Con. I	5	5	5	4	9	4	7	3	3	5	3	3	7	3	4	3
	Con. II	6	5	4	6	7	5	6	6	3	3	3	5	3	3	4	5
5	Ex. I	7	7	7	7	3	5	3	3	7	6	3	6	5	4	5	5
	Ex. II	1	6	9	7	7	9	9	9	1	1	2	2	1	1	1	1
	Control	9	7	8	8	3	5	3	3	5	1	5	4	3	3	6	5
	Con. I	3	3	6	6	1	3	7	4	7	5	5	5	3	3	3	4
	Con. II	7	7	7	6	7	3	8	7	5	7	3	6	3	5	3	4
6	Ex. I	7	7	7	5	3	5	5	5	7	7	7	7	7	5	5	7
	Ex. II	7	6	7	7	7	7	7	7	3	3	3	3	3	3	3	3
	Control	7	6	7	7	5	3	5	5	9	7	7	7	7	7	5	5
	Con. I	7	3	3	3	3	3	3	3	5	7	7	7	9	7	7	7
	Con. II	5	6	5	3	5	3	5	5	3	9	7	9	3	5	5	5
7	Ex. I	2	3	6	6	8	7	3	5	8	5	4	6	7	6	5	5
	Ex. II	8	4	7	8	7	8	6	8	7	2	1	1	4	6	2	2
	Control	7	8	9	8	3	5	4	6	4	3	3	2	4	4	3	3
	Con. I	6	2	3	3	6	9	6	7	6	8	8	7	6	8	8	7
	Con. II	5	7	7	8	6	3	5	6	5	6	7	5	5	5	6	5
8	Ex. I	5	7	3	5	7	3	5	5	6	7	8	6	5	5	6	6
	Ex. II	3	2	8	3	5	7	8	7	2	4	5	3	2	3	2	2
	Control	6	4	7	7	5	6	5	3	9	3	7	7	7	6	7	7
	Con. I	3	7	8	2	8	4	8	9	5	8	2	8	3	3	2	3
	Con. II	5	6	3	7	3	3	6	3	7	6	8	9	5	5	4	5
9	Ex. I	7	6	6	6	3	3	4	4	9	8	5	5	6	4	6	5
	Ex. II	6	6	7	6	7	7	7	7	5	4	3	2	6	5	4	4
	Control	9	8	8	8	6	3	4	8	8	7	6	4	6	5	6	7
	Con. I	5	7	7	7	4	3	4	3	7	7	4	5	5	3	4	6
	Con. II	8	6	8	6	4	4	5	6	8	8	5	4	4	4	6	6

Table 37. Analysis of variance of the results of the second set of texture evaluation.

Characteristic	Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio	Probability Level
Firmness	Judge	8	111.6	13.95	4.6453	<0.005
	Day	3	9.9278	3.3093	1.1019	>0.100
	Sample	4	71.8667	17.9667	5.9829	<0.005
	Judge x Day	24	57.8222	2.4093	0.8023	>0.100
	Judge x Sample	32	104.7333	3.2729	1.0899	>0.100
	Day x Sample	12	30.7111	2.5593	0.8522	>0.100
	Judge x Day x Sample	96	288.2889	3.0030	1	
	Total	179	674.95	0	0	
Smoothness	Judge	8	168.64	21.081	12.926	<<0.005
	Day	3	1.5278	0.5093	0.3123	>0.100
	Sample	4	80.778	20.194	12.382	<<0.005
	Judge x Day	24	74.822	3.1176	1.9116	0.025
	Judge x Sample	32	239.52	7.4851	4.5895	<<0.005
	Day x Sample	12	36.333	3.0278	1.8565	0.050
	Judge x Day x Sample	96	156.57	1.6309	1	
	Total	179	758.19	0	0	
Glueyness	Judge	8	109.21	13.651	6.3732	<<0.005
	Day	3	14.95	4.9833	2.3265	0.100
	Sample	4	329.81	82.453	38.493	<<0.005
	Judge x Day	24	76.7	3.1958	1.492	0.100
	Judge x Sample	32	183.79	5.7434	2.6813	<0.005
	Day x Sample	12	71.967	5.9972	2.7998	0.005
	Judge x Day x Sample	96	205.63	2.142	1	
	Total	179	992.06	0	0	
Overall	Judge	8	60.611	7.5764	9.2379	<<0.005
	Day	3	0.0611	0.0204	0.0248	>>0.100
	Sample	4	149.2	37.3	45.48	<<0.005
	Judge x Day	24	32.989	1.3745	1.676	0.050
	Judge x Sample	32	213	6.6563	8.116	<<0.005
	Day x Sample	12	23.467	1.9556	2.3844	0.010
	Judge x Day x Sample	96	73.733	0.8214	1	
	Total	179	558.06	0	0	

If, however, their tendency is consistent in every session of testing, this does not create a problem in the subsequent statistical analyses of the results. This, with few exceptions, appears to be the case in the second set of tests, the results of which are shown in Table 36.

The statistical analysis of the results from the second set shows once again significant differences among both samples and judges (Table 37). The interaction between judge and sample in every case except firmness is significant at 0.005% probability level. This would indicate that, with the exception of firmness, the judges differ greatly in their perception of the textural characteristics of mashed potatoes. This may be due to differences in their concepts of an ideal product, or to the imperfect definitions given to the characteristics, or both. This assumption was somewhat confirmed when the panelists were interviewed individually after the final session of the tests. The interviews revealed that even though their method of judging was essentially the same, i.e. from the mouthfeel on chewing, their interpretation of the feeling for each characteristic was somewhat different and largely governed by their personal preference on the texture, and to some extent on the flavor of the product. The firmness was essentially judged from the resistance of the product to the force applied on chewing. The judging of smoothness was governed, to a certain extent, by personal preference. There

seems to be two distinct preferences. One group (judges 1, 2, 4, 7, and 8) preferred the product to be slightly grainy, thus tended to give higher score for smoothness in the samples with coarser texture. The other group (judges 3, 5, 6, and 9) preferred smooth mashed potatoes, and hence tended to give lower scores.

The glueyness, on the other hand, was largely agreed upon by all judges. Due to the difficulties in defining this characteristic precisely, different judges seemed to perceive the glueyness slightly differently. From the interviews, the majority of the panelists judged the glueyness of the samples by the way they stuck between the teeth, gum and the roof of the mouth, while some also included the elastic response of the samples on chewing in their judgment. There were some who associated elastic response with the firmness of the product.

The comments made by some panelists also revealed that their preference on other characteristics of mashed potatoes was also different. White color, for example, was preferred by some, while creamy or light yellow by the others. Many panelists strongly disliked skim milk flavor and "additive" or "soapy" flavor in mashed potatoes as exemplified by the commercial products used in the tests. The skim milk flavor is attributed to the high proportion of skim milk powder in the commercial granules. The "soapy" flavor is thought to be due to the high level of additives, particularly surfactants, in the commercial potato flakes.

The overall view of the statistical analysis suggested that there might be some correlation between individual characteristics, i.e. firmness, smoothness, glueyness, and overall textural quality as judged by the panel. This hypothesis was verified when average daily scores for each characteristic of each sample (Table 38) were plotted against one another and their correlation coefficients computed (Table 39). Table 39, Figures 41, 42, and 43 show that when smoothness and glueyness are plotted against overall, and smoothness against glueyness, their correlation coefficients, -0.7484, 0.8548, and -0.7459 respectively are significant at 0.01 probability level with that of glueyness against overall being the highest. This may suggest that glueyness and smoothness were associated most strongly with the overall textural quality of mashed potatoes. Between these two, glueyness was most strongly correlated with the judges' preference towards the samples, with the more gluey samples being liked the least. The strong correlation between glueyness and smoothness may also suggest that the smoothness of mashed potatoes may be derived from their glueyness or pastiness. This is probable considering that the more gluey product results from the greater amount of starch released from the broken cells to form a matrix of smooth, sticky gel.

As the overall textural quality of mashed potatoes correlates most strongly with glueyness, it was thought

Table 38. Average daily scores of each characteristic of each sample.

Characteristic		Firmness	Smoothness	Glueyness	Overall
Sample	Day				
Ex. I	1	5.78	6	7.11	6.11
	2	5.89	5.44	6.33	5
	3	5.67	4.89	5.33	5.78
	4	5.89	5	6	5.67
Ex. II	1	5.33	6.44	3.67	3
	2	5.56	7.33	2.44	3.67
	3	7	7.11	2.33	2.67
	4	5.33	7.11	2.44	3
Com. I	1	4.89	5.44	6	5.56
	2	5	5.11	6.89	4.89
	3	5.78	6	5.56	5
	4	4.89	5.33	6.33	5.56
Com. II	1	5.44	6	5.44	4.44
	2	6.56	4.33	7	5.33
	3	5.78	6	6.22	5.33
	4	6.56	5.89	6.33	5.44
Control	1	7.22	5.22	6.78	5.22
	2	6.22	5.67	4.67	5.33
	3	7.56	4.67	6.33	5.67
	4	7.33	4.89	4.22	4.78

Table 39. Correlation coefficients between average daily scores of each characteristic.

	Firmness	Smoothness	Glueyness	Overall
Firmness	1	-0.2647	0.0087	0.0602
Smoothness	-0.2647	1	-0.7459*	-0.7484*
Glueyness	0.0087	-0.7459*	1	0.8548*
Overall	0.0602	-0.7484*	0.8548*	1

* Significant at 0.01 probability level (Snedecor, 1946).

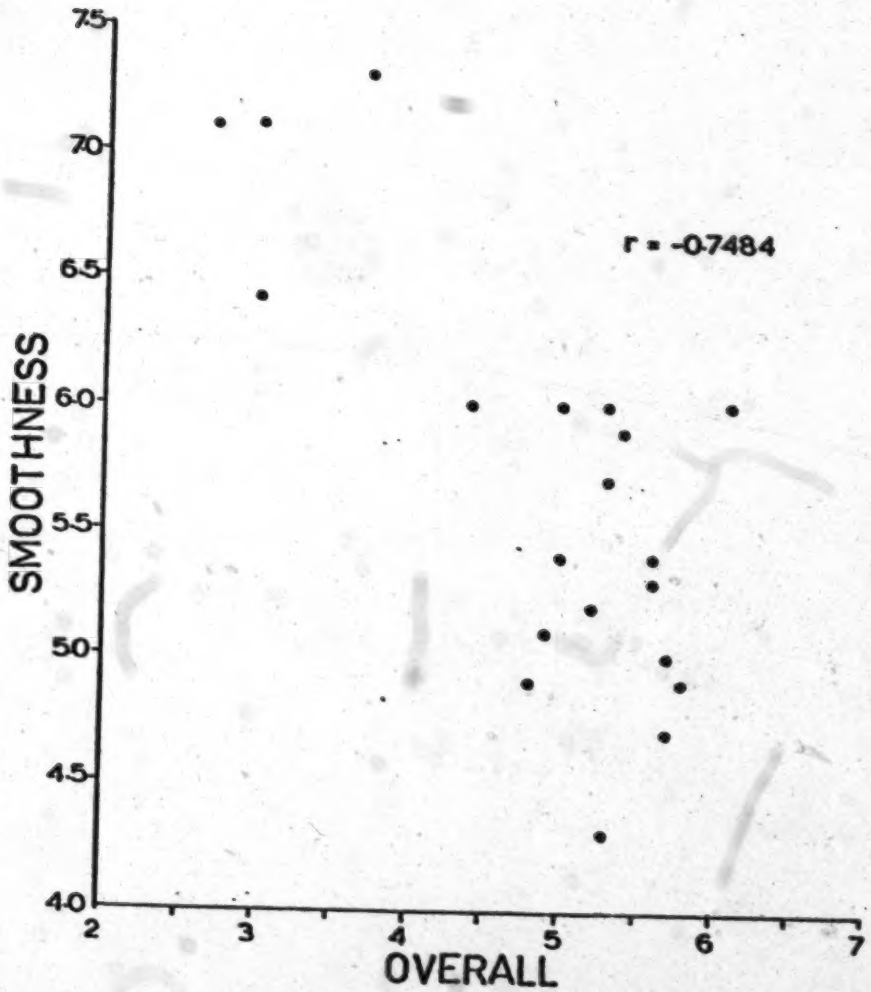


Figure 41. Average daily scores of smoothness vs average daily scores of overall.

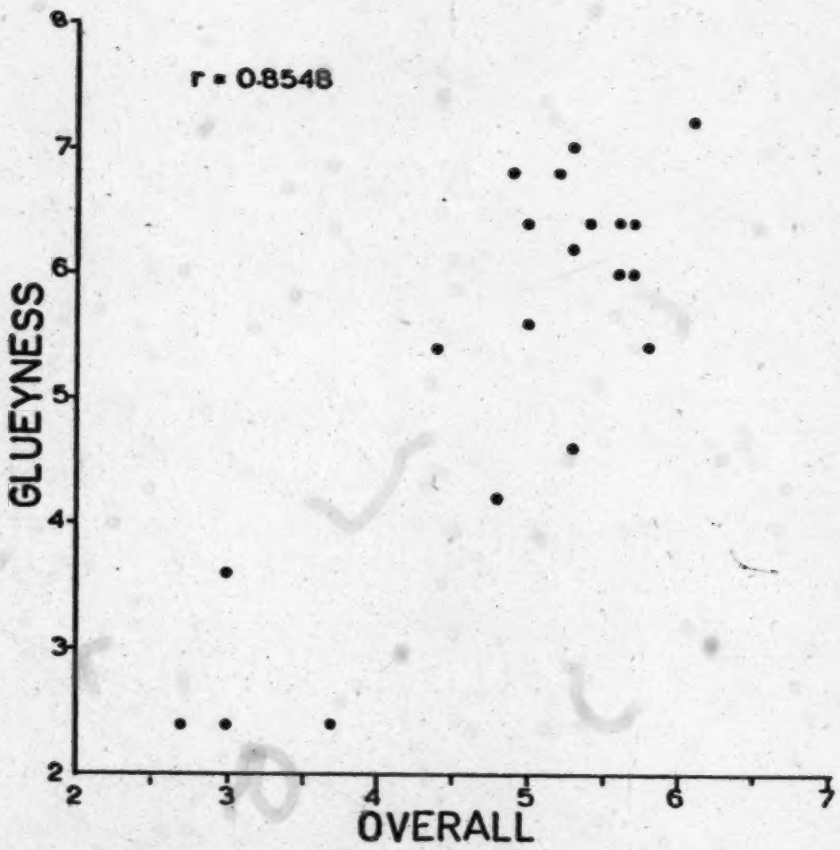


Figure 42. Average daily scores of glueyness vs average daily scores of overall.

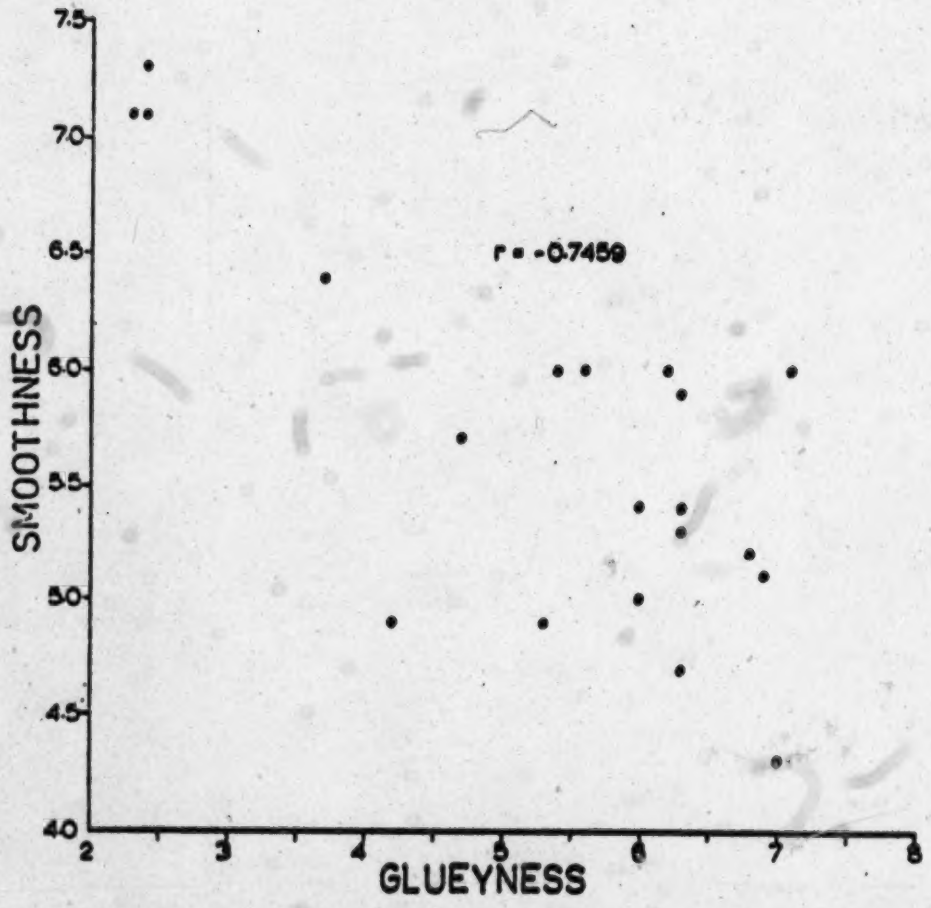


Figure 43. Average daily scores of smoothness vs average daily scores of glueyness.

Table 40. Summary of the Duncan's New Multiple Range Test of the mean scores of the overall characteristic of the samples.

	Group*				
	1				2
Sample	Ex. I	Control	Com. I	Com. II	Ex. II
Mean score	5.639	5.25	5.25	5.139	3.083

* There is no significant difference among the samples in group 1, but samples in group 1 are significantly different from that in group 2 at 0.01 probability level.

possible to use this parameter for objective measurement of the quality of the product, using a mechanical instrument. If the objective method proved successful then perhaps it could replace subjective analysis, which relies strongly on human factors, in measuring textural quality of mashed potato product. The development of the objective method is reported in Section C. VII. 2..

When the overall characteristic of the samples were averaged over four days results and analysed, using the Duncan's New Multiple Range Test (Duncan, 1955), the results (Table 40) shows that sample Ex. II, which was specially processed to represent the most gluey product, was rated significantly lower (at 0.01 probability level) than other samples. Samples Ex. I, Com. I, Com. II, and Control were not significantly different from one another. Sample Ex. I, however, was given highest average score, higher than even the control sample which was the freshly mashed potatoes. The comments from some panelists also suggested that the flavor and color of the sample Ex. I resembled more closely those of the freshly mashed potatoes than any other sample used in this study.

2. Objective measurement of the texture

The interpretation of the results of the objective measurement of firmness in this study is somewhat different from that adopted by Friedman et al. (1963). This is due

largely to the fact that, though the principle of measurement is the same but the instrument used is somewhat different. In the case of the texturometer used by Friedman et al. the plunger, on compressing the sample, moves up and down repeatedly and automatically on to the sample within a set clearance from the strain gauge sensing plate.

A typical texturometer curve is shown in Figure 44. Friedman et al. (1963) interpret the value of hardness or firmness of the sample from the height of the curve B1 divided by the volts input, and the adhesiveness is represented by area B3.

In the present study, the movement of the plunger up or down was controlled manually, a typical curve of which is shown in Figure 22. The area A1, which represents the work done by the plunger to compress a sample down to a certain height, was thought more appropriate in this case to be the value of firmness of the sample. Area A2, which is the work done to pull the plunger back from the compressed sample - thus relating to the adhesion between the plunger surface and the sample, is the value of the adhesiveness or glueyness of the sample.

When the results of the measurements (Table 41) were analysed statistically (Table 42), the variance ratios show that in every case only the differences between the samples are significant at 0.005 probability level. The variance ratios of the other factors and interactions are

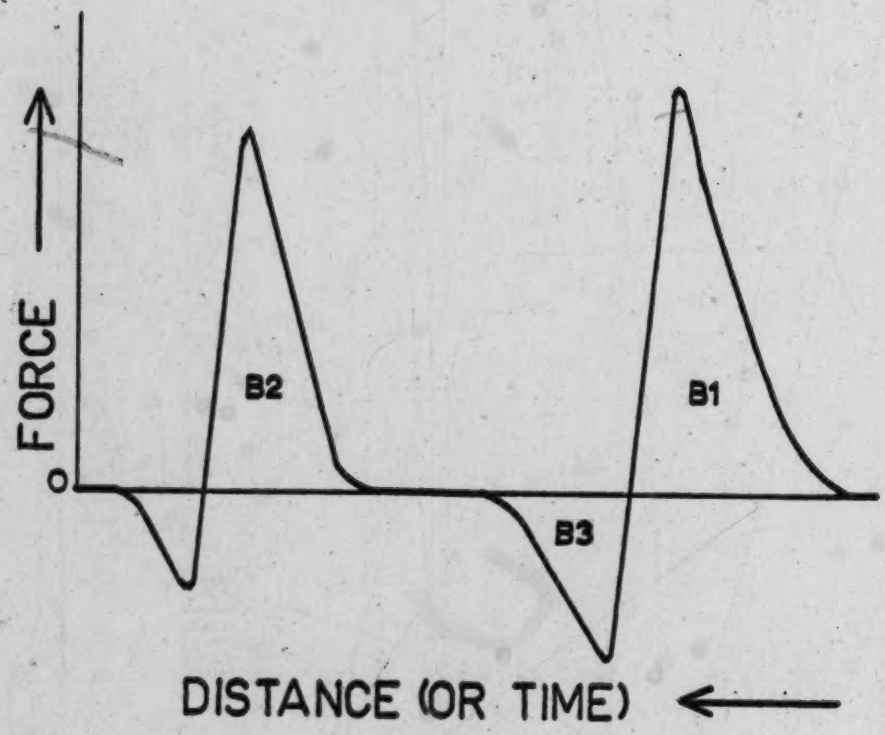


Figure 44. A typical General Foods Texturometer curve. (Adapted from Friedman et al., 1963).

Table 41. Results of objective evaluation of firmness and glueyness, and bulk density of the mashed potato samples.

Sample	Parameter: Objective Firmness,* Relative Area Under A1				Objective Glueyness,* Relative Area Under A2				Bulk Density,** gm./c.c.		
	Day: 1	2	3	4	1	2	3	4	2	3	4
Ex. I	0.1587	0.1613	0.1520	0.1587	0.0147	0.0153	0.0147	0.0137	0.9937	0.9928	0.9897
Ex. II	0.1197	0.1090	0.0937	0.0963	0.0477	0.0513	0.0780	0.0730	1.0141	1.0051	1.0056
Com. I	0.1283	0.1223	0.1410	0.1260	0.0070	0.0063	0.0083	0.0070	0.9888	0.9969	0.9846
Com. II	0.1920	0.1887	0.1887	0.1827	0.0177	0.0140	0.0153	0.0137	0.9835	0.9762	0.9798
Control	0.1900	0.1430	0.1590	0.1803	0.0210	0.0310	0.0173	0.0217	1.0040	0.9839	0.9948

* Average of three measurements.

** Average of two measurements.

Table 42. Analysis of variance of the objectively measured firmness, glueyness, and density results.

Parameter	Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio	Probability Level
Firmness	Sample	4	0.07237	0.00431	32.672	<<0.005
	Day	3	0.00048	0.00016	1.223	>0.100
	Sample x Day	12	0.00158	0.00013	1	
	Total	19	0.01930	0	0	
Glueyness	Sample	4	0.00773	0.00193	31.720	<<0.005
	Day	3	0.00007	0.000026	0.432	>>0.100
	Sample x Day	12	0.00073	0.000061	1	
	Total	19	0.00854	0	0	
Density	Sample	4	0.00125	0.000313	9.932	<0.005
	Day	2	0.000115	0.0000576	1.829	>0.100
	Sample x Day	8	0.00025	0.000032	1	
	Total	14	0.00162	0	0	

not significant. This indicates that the measurement method is sensitive enough to differentiate firmness, glueyness, and density among samples, and that the variation of the results of measurement from day to day within a sample is not statistically significant. Hence, the methods of measurement and interpretation of the results are reliable for the purposes.

The correlation coefficients (Table 43; Figures 45, 46, 47, and 48) show that those between subjective glueyness and objective glueyness; overall and objective glueyness; subjective smoothness and objective glueyness; overall and density; density and objective firmness; density and objective glueyness; and density and subjective glueyness are significant at the 0.01 probability level. Those between subjective firmness and objective firmness; overall and objective firmness; and density and subjective firmness are not significant. The high correlation coefficients between objective glueyness and subjective glueyness, and overall and objective glueyness again indicate that glueyness is the most promising characteristic to be used as a measure of the textural quality of mashed potatoes, and that this characteristic can be reliably measured objectively.

Objective firmness does not have significant correlation coefficient with either its subjective counterpart or with overall. This appears to suggest that

Table 43. Correlation coefficients between subjective and objective evaluations of mashed potatoes.

Cofactors	Correlation Coefficient	Probability Level
Subj. firmness x obj. firmness	0.4628	not significant
Subj. glueyness x cbj. glueyness	-0.8940	<0.01
Overall x obj. firmness	0.3392	not significant
Overall x obj. glueyness	-0.8833	<0.01
Subj. smoothness x cbj. glueyness	0.7608	<0.01
Overall x density	-0.7223	<0.01
Density x obj. firmness	-0.7316	<0.01
Density x obj. glueyness	0.7303	<0.01
Density x subj. firmness	-0.0878	not significant
Density x subj. glueyness	-0.8585	<0.01

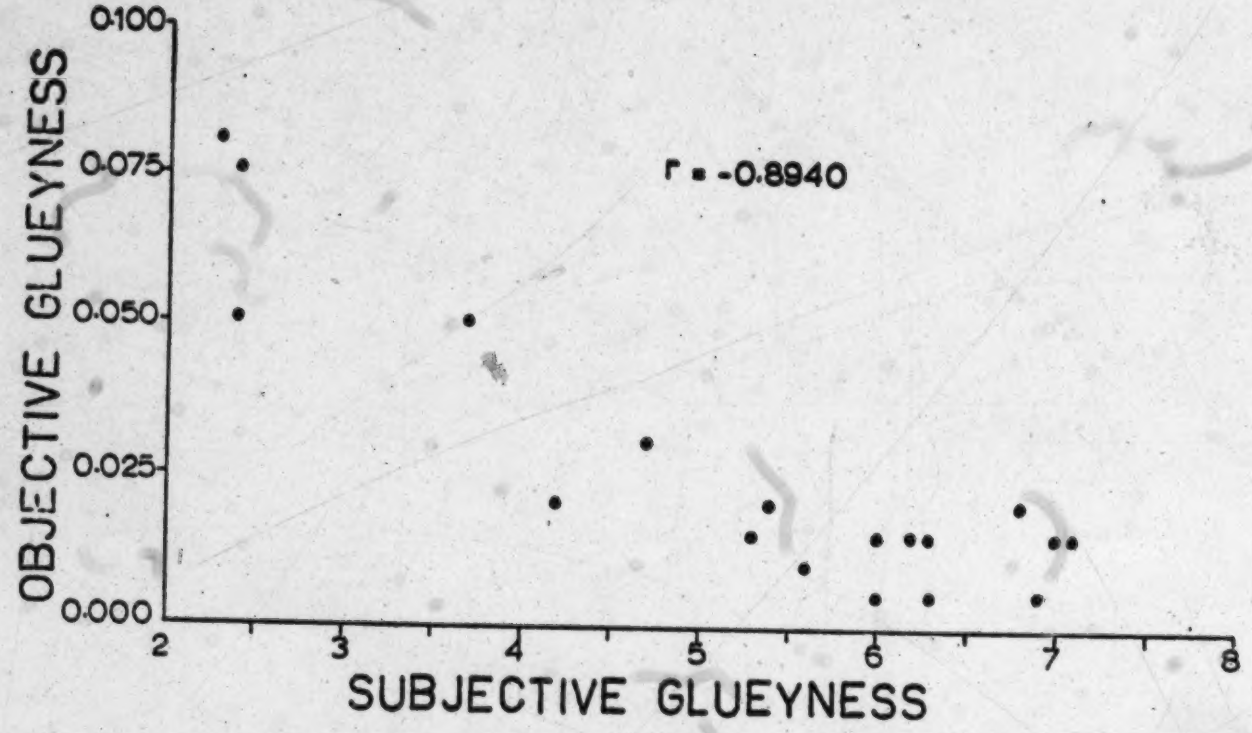


Figure 45. Objective glueyness vs subjective glueyness.

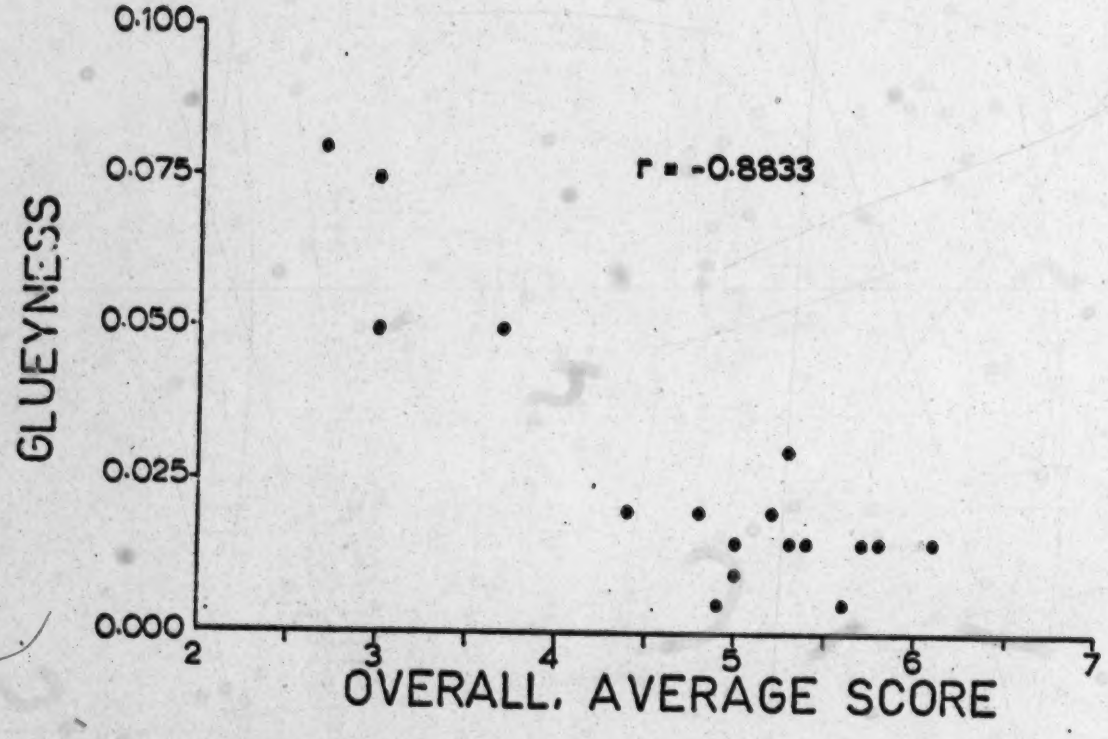


Figure 46. Objective glueyness vs subjective overall (average scores).

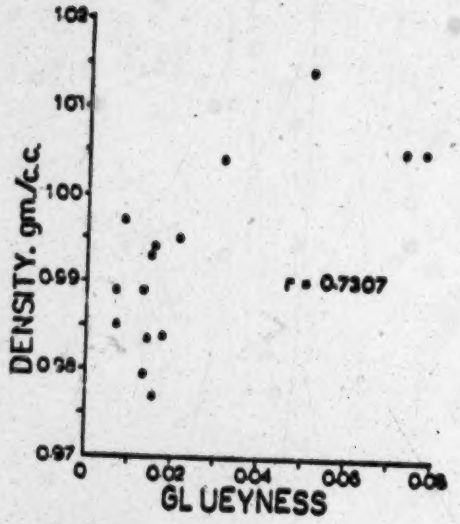


Figure 47. Density vs objective glueyness.

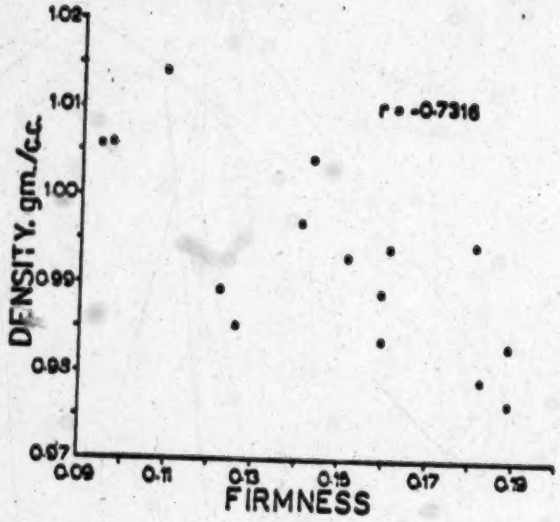


Figure 48. Density vs objective firmness.

firmness, either subjectively or objectively evaluated, is not an adequate measure for the textural quality of mashed potatoes, or alternatively that the range of firmness of the samples tested was too small to be a useful indication of the textural quality of the materials.

The significant correlation coefficients between density and both subjective and objective glueyness may be interpreted that the glueyer product, i.e. the product with higher amounts of released starch gel, tends to be more compact. This is conceivably due to the tighter gel network which covers the whole matrix of the mashed potatoes.

It is thus appropriate to propose that for the purpose of the quality control of the texture of the product, a control chart on which a maximum tolerable glueyness level is specified should be used, together with the instrument basically similar to that used in this experiment, to determine whether the product is acceptable texturally. The maximum tolerable level of glueyness can be standardized for each unit of instrument and each set of conditions used in the measurement. Using samples with a wide range of textural quality, prejudged by a trained sensory panel, as standards, the tolerable level can thus be set.

The instrumentation can, of course, be improved for higher sensitivity and more accurate control, but it is

believed that the basic principles of the method is adequately reliable for both quality control and product development purposes. For the products from similar raw material and same processing technique, this method should be ideal. For the products from different raw material and different processing techniques, however, care must be taken to ensure that the consistency, as judged by a trained panel, of the products on reconstitution should be similar for a meaningful comparison. Once the reconstitution ratio for each product is set to produce similar consistency, as in the present experiment, the method should prove effective as a means for comparison.

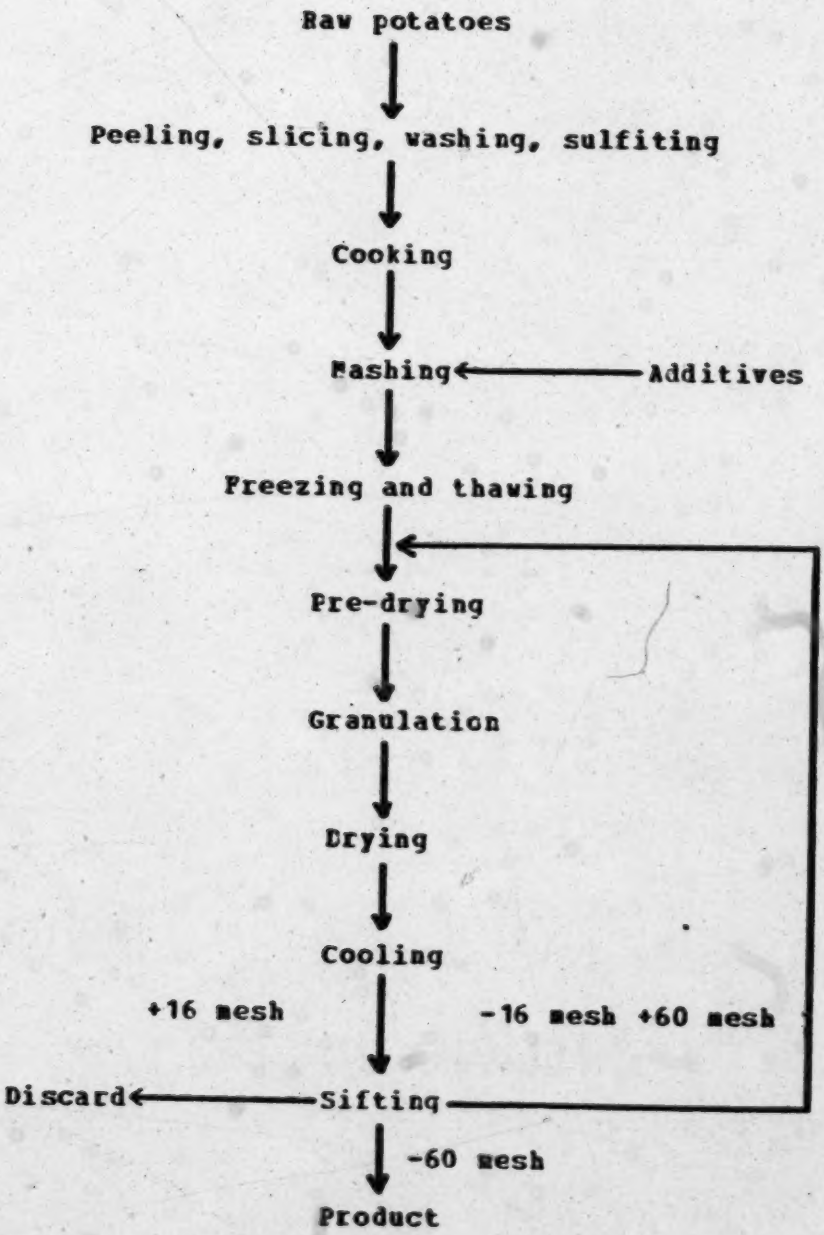


Figure 49. Flow chart for the proposed freeze-thaw process.

SECTION D. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The present investigations show that the freeze-thaw technique, along with the use of small quantities of surfactants, makes possible a direct process for the production of potato granules without any add-back. The flow chart as shown in Figure 49 is thus adopted for the proposed process.

The product produced in these experiments is of a high quality, comparable to or better than existing products and freshly mashed potatoes. In particular, the following conclusions can be made with respect to the quality of the product:

1. Both the flavor and the color of the product are very close tc those of freshly mashed potatoes.

2. The freeze-thaw process yields a product with a very low percentage of broken cells, which contributes to the lack of glueyness of the reconstituted product.

3. The freeze-thaw granules reabsorb water rather more readily than some commercial add-back granules and much more readily (and more rapidly) than potato flakes. The freeze-thaw granules produce an instant mashed potatoes with firmer texture with less sclid material than other granules, which will tend to make the freeze-thaw granules more

economical to use than commercial add-back granules.

4. The reconstitution ratio (product to water) is more uniform than some commercial products when the granules are reconstituted to the same consistencies.

The present studies lead to the conclusion that the use of the freeze-thaw technique leads to a process which has a number of advantages over the add-back process. These advantages are as follows:

1. The process involves fewer steps in the processing in that several mixing, pre-cooking, conditioning, and recycling steps are eliminated and replaced by the freezing, thawing and pre-drying steps. It is expected that the elimination of these important steps in the add-back process will make the process much easier to control.

2. The average residence time of the material in the freeze-thaw process is considerably less than that in the add-back process, with the possibility of improvements in the nutritional quality of the product.

3. Because recycling of large quatities of product is eliminated, the dryers necessary for the freeze-thaw process will be considerably smaller than those for the add-back process. The heat load for evaporation will be the same for the two processes, but the smaller dryers will require

lower total air flows for transport of the material, and will probably have significantly lower heat losses.

4. The freeze-thaw technique gives a constant rate drying period down to moisture levels at which granulation can take place. This means that the pre-drying, which removes about 50% of the moisture, can be done fairly rapidly without the use of unduly high temperatures.

5. The freeze-thaw process may be able to handle potatoes with a wider range of specific gravities and moisture contents than the add-back process; in particular the process has been operated with potatoes with as low as 19% total solids, whereas the minimum total solids for the add-back process is considered to be 20%.

6. The freeze-thaw process appears, in the experimental equipment at least, to give a significantly lower proportion of oversize material in the product than is obtained in other processes.

These studies lead to a number of conclusions relating to the process and process equipment, as follows:

1. The rate of freezing appears to be controlled by the rate of transfer of heat to the surface, rather than by the rate of heat conduction through the frozen material to the surface of the potatoes.

2. A stirred bed dryer can be used for pre-drying

of the cooked, frozen and thawed mashed potatoes. Stirring speed of approximately 1 ft/sec is sufficient to give uniformity within the bed and keep the drying at a maximum rate, but are not great enough to do a significant amount of damage to the cells. The time taken to pre-dry the material from approximately 75% moisture to approximately 40% can be as short as 10 minutes.

3. Granulation can be accomplished at moisture contents in the range of 42-35% moisture. Stirrer speed up to about 25 ft/sec are satisfactory, giving rapid granulation with little cell damage.

4. Air classification appears to be useful in both the pre-drying and granulation steps in that air velocities can be used such that the fine, relatively dry particles are lifted out of the active region of the bed, and the larger and denser particles remain in the lower part of the bed where they are subjected to a greater extent to the heating and stirring action.

A number of conclusions can be made with respect to the effects of the temperature of mashing, the use of freeze-thaw technique and the use of surfactants on the material and the process. These are as follows:

1. The temperature of the potatoes has a strong effect on the strength of the materials (starch and pectic substances) which bind the cells together: the higher the

temperature the less strongly are the cells bound together.

2. The freezing and subsequent thawing of the cooked potatoes also reduces the strength with which the cells are bound together.

3. After freezing and thawing the strength of the intercellular binding materials is further reduced by increasing the temperature of the potatoes.

4. Low broken cell counts in the mashed material are generally associated with conditions which give low strengths of intercellular binding materials.

5. Mashing before complete thawing has occurred gives high percentages of broken cells.

6. Low concentrations of surfactants can be used to reduce the amount of free extracellular starch available for gel formation and cell binding during the pre-drying and granulation stages. There are indications that water-soluble pectic substances may be affected by surfactants in a manner similar to starch. In the case of starch, Myvatex which is a mixture of components appears to be more effective than Myverol which is essentially a single component surfactant. The reverse appears to be the case with water-soluble pectic substances.

Several conclusions can be made with respect to experimental techniques and analytical methods, as follows:

1. The carbazole method of McComb and McCready (1952) can be used in the presence of low concentrations of starch (<0.04%) if a correction based on the blue value of the solution is applied.

2. The drying rate can be satisfactorily determined from the decrease in temperature of the air as it passes through the bed. Corrections can be made to take account of heating or cooling of the bed. This method obviates the taking of samples or the weighing of the material in the bed, and has the added advantage that the uncertainties inherent in graphical differentiation of weight or moisture content vs time curves are eliminated.

3. Glueyness, either measured objectively or by the texture panel appears to be the most important textural characteristic in determining the overall preference rating. It would appear that the objective glueyness measurement will be of some use in evaluation of the overall textural quality of the mashed potatoes in process development and in quality control.

Process Recommendations

It is believed that the freeze-thaw process can be made continuous. A suggested process is outlined below:

1. Peeling, slicing, washing and sulfiting: These are standard operations and can be done using any of the

presently existing methods.

2. Cooking: This can be either by steam or water. Steam cooking is preferable in that losses of soluble components are lower than with water cooking, and the steam process is easier to control.

3. Mashing: This should be of short duration and should be done at a high temperature. Surfactants (and other additives that may be required) should be added at this stage.

4. Freezing and thawing: The freezing can probably be done in a continuous blast freezer with the mashed material being carried on mesh belts. The thawing can probably be done in a similar manner, possibly using exhaust air from the dryers.

5. Pre-drying, granulation and drying: It may be possible to adapt the U-section stirred troughs described by Hendel et al. (1961), with air being blown through perforations in the bottom of the troughs. Air velocities and temperatures can be set to different values at various parts of the pre-drying and granulating troughs to classify and transport the solids as desired. The stirring and granulating arms can be designed to aid product movement if this is found to be necessary. Final drying could be done in a fluid-bed dryer or in an air-lift dryer.

Alternatively, a vertical multistage fluid-bed

dryer such as that described by Sloan (1967) may prove to be suitable. It is suggested that the pre-drying be done in the upper level, the granulation on the next lower stage, and the final drying on the bottom stage.

6. Cooling, sifting and packaging: These are relatively standard processes for which various types of equipment are readily available.

There is a considerable amount of detailed design which must be done before a plant using the freeze-thaw technique can be set up.

The cost of refrigeration is one major item which does not occur in the add-back or flake processes and will offset savings made by elimination or reduction in size of equipment used in the add-back process. It may be possible to reduce the cost of refrigeration considerably in areas which have long winter periods of sub-freezing atmospheric temperatures, e.g. central or southern Alberta or the other prairie provinces of Canada, but have a summer long enough to provide a good growing season. If necessary, short periods of intense cold could be used to freeze the cooked mashed potatoes which could then be held for subsequent processing.

The cost of production can be reduced further by recycling of the drying air. For example, the exhausted air in the drying step can be slightly reheated and reused in

the pre-drying step. The exhaust from the pre-drying step can be used further to thaw the frozen potatoes in the thawing tunnel. The cool exhaust air from the thawing tunnel can be used to cool the hot mashed potatoes, in preparation for freezing, before being finally expelled.

Recommendations for Further Study

As well as studies directly related to scaling up the process, several areas could benefit from further study, as follows:

1. Effects of raw material on processing, and on quality of the final product: In particular, dry matter content, specific gravity, variety, maturity, and cultural history are factors which should be studied. Various pre-processing treatments may be found necessary to improve processing or product quality with some raw potatoes, and these treatments will need to be determined.

2. Role of pectic substances in cell structure and intercellular binding: The ratio of soluble to insoluble pectic substances in the cooked potatoes which gives maximum cell wall strength and minimum intercellular binding could be determined. Related to this is the incompletely understood role of calcium in protopectin linkages in the raw and cooked potatoes, and the role of various surfactants in affecting gel strength.

3. Factors affecting reconstitution ratio: It is not known precisely why the freeze-thaw process tends to have a more uniform and higher reconstitution ratio than some add-back granules. The reasons for these phenomena need to be understood so that the process can be run more rationally and possibly improved further. It may be that the ice crystals cause occurrence of minute holes in the cell walls which increase the permeability of the cell walls. Electron microscopy and freezing rate studies will probably be useful in this area of study.

4. Textural characteristics: The rheological parameters that are involved in the subjectively perceived textural characteristics need to be more precisely defined, and objective measurements need to be improved so that straightforward instrumental method of texture evaluation can be developed for use in further product development and quality control. The relationship of the various rheological parameters to the chemical and physical properties of the material (such as concentration of amylose and pectic substances, relative amounts of intracellular and extracellular water on reconstitution, etc.) also need to be determined.

5. Nutritional quality: It is known that potatoes can be a significant source of vitamin C in the diet, particularly when potatoes are a staple component. The quantities of this vitamin remaining after processing may be

greater than those in add-back granules because of the shorter and milder heat treatment in the freeze-thaw process. The levels of vitamin C should be checked, and the process modified, if possible, to maximize the retention of this nutrient.

6. Storage properties: The factors affecting product deterioration on storage need to be studied so that appropriate storage conditions can be specified. There may be significant differences between the storage life of freeze-thaw granules and that of add-back granules, if in fact the freezing and thawing causes significant changes in cell structure or arrangement of cell components.

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